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ELECTRIFYING DENMARK

A symmetrical history of central and decentral electricity supply until 1970

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Introduction:
Progress and symmetry in the historiography of electricity supply

From the last decades of the nineteenth century to the decades after the Second World War, the supply of heavy current electricity was developed from a curiosity to an integrated part of the technical and social structure of modern society. Denmark, as many other Western countries, had been covered by a giant technical structure that provides the basis of electricity supply today: By the 1960s electricity production had been centralized in few very large power stations, which fed a system of high voltage power lines, through which electricity was transported to consumers across the country. Moreover, national systems had been interconnected; in Europe, by the mid 1960s consumers in Northern Norway were electrically linked to consumers on Southern Sicily.[1] And coinciding with the emergence of this giant technical structure, heavy current electricity became a central source of energy in modern, ever more energy intensive societies, and made light, power and heat widely available by a simple pull of a switch.

There exists a considerable literature that describes and analyses the physical development of electricity supply, and an emerging body of research on the role of electricity in societal transformations. Certainly, the complaint of the French poet and philosopher Paul Valéry that the 'notable phenomenon' of 'the conquest of the earth' by electricity was neglected by traditional history - despite its having 'more meaning and greater possibilities of shaping our immediate future than all the political events combined' - has been taken up: It was, for instance, cited in the authoritative works of the American scholars Thomas Hughes, whose *Networks of Power* (1983) analysed the growing scale of the electricity supply in England, Germany and the United States in a new vocabulary of an expanding technological system, and David Nye, whose *Electrifying America* (1990) complemented this study of electricity production by an analysis of how several social institutions - the city, factory, home and farm - adopted and used electricity in the United States.[2] And, particularly with regard to the study of the supply side of electricity, other authors have described the rise of the electricity supply system in countries traditionally less in focus of historians of technology. In Denmark, this includes a couple of analytic studies in the early 1980s and a narrative 'cultural history of electricity supply' in the early 1990s. Denmark is also included in a more recent comparison of the growing electrical networks in the Nordic countries.[3]

It is also the development of electricity supply, resulting in the nearly complete dominance of what I shall call the 'technical configuration of centralized electricity supply' or 'centralized electricity supply system' in Denmark by the 1960s, that is the subject of this dissertation. Yet it differs from the above studies in its strategy and vocabulary. The above studies focus upon the expansion of the electricity supply system, which they describe as a succession of different configurations of electricity supply with still larger scales of supply. This leaves little or no room for the fate of small scale supply systems, once a newer, larger scale system has been introduced. Moreover, they explain this succession in terms of a technical-economical superiority of the larger scale systems, enabling them to oust their smaller scale predecessors. This even concerns studies with some constructivist elements, emphasising for instance, like Hughes, that the invention of larger scale supply systems might rely upon historical contingencies and social processes; that their importance reflects a particular kind of capitalist culture, where interest on capital was a primary criterion of judgement; that their factual shape (or 'style') was actively varied with local natural, technical and social preconditions; and that the environment in principle could break the momentum of large scale sociotechnical systems and change the course of development: Despite such awareness of the interrelation of the technical and the social, they display little or no doubt that once invented, larger scale electricity supply had an intrinsically superior economy to smaller scale supply, either by reference to economies of scale, or to more advanced economic concepts such as an improved 'load factor' (the machinery was more fully exploited - and the return on investment increased - if many consumers with complementary loads were connected in one supply system) or 'economic mix' (the load could be economically distributed on different power sources interconnected in one system). In these studies, the economic factor is taken to exert - in Hughes' words - a 'soft determinism' on the development of electricity supply in the direction of scale increase.[4]

Although it acknowledges the strength of these studies to study important mechanisms of system expansion, this dissertation adopts neither the study of electricity supply according to a succession model, which is a consequence of the focus upon the process of scale increase, nor the explanation of this process in terms of a technical or economic rationality (although it can of course not deny that for instance large systems enjoy scale advantages). Instead, it seeks to (re)describe the development of electricity supply in Denmark in a framework of the co-existence of old, small scale (in this study also termed 'decentral') and newer, larger scale configurations of electricity supply for the entire period under consideration. Moreover, the dynamics of each configuration are described not from an 'objective' point of view, but from the point of view of the actors that owned and operated the different and competing electricity supply systems.

There are two reasons for this diverging strategy. The first is the current historical interest in the fate of decentral electricity supply. It has been observed that the old, small scale electricity supply systems might survive even after the introduction of new, larger scale ones, but this has never been analysed systematically. For normally these are regarded as mere remainders of past times, and at best seen as relatively unimportant niche technologies. But in fact small scale electricity supply systems might be of considerable importance several decades after newer, larger scale configurations of electricity supply were introduced. It is understandable that this has received little attention, as the growth of 'the system' in general (justifiably) has been considered the main event in the history of electricity supply. However, in the light of the renewed success of decentral electricity supply in the current electricity supply structure, where decentral electricity supply systems (re)appear in middle-sized and smaller towns, industrial firms, and also single or groups of farms in the form of combined heat and power production systems or wind-electric turbines, it is interesting to re-open the story of the successful centralization of electricity supply with a focus upon these decentral supply systems.

The second reason concerns the explanation of the process of scale increase. This dissertation rejects the presupposition that larger scale configurations of electricity supply possessed an inherent technical and economic superiority relative to smaller scale systems, and that the centralization process had an unambiguous technical-economical rationality in a society that values these aspects. An equal treatment of decentralized and centralized systems allows for a re-description of the history of electricity supply with particular sensitivity to, how actors of decentral as well as centralized systems could claim - and had reason to claim - technical and economical superiority for using their type of supply system in their specific context. Technical and economical superiority, in other words, were by no means intrinsic properties of newer, larger scale supply systems, but properties of systems relative to a context. If this is so, one needs alternative categories for describing and explaining the dynamics of the individual electricity supply system, which can account for both the consolidation of old, decentral systems until at least the Second World War, as well as the nearly complete success of centralized electricity supply in the post war period: For by 1970, the latter indeed accounted for about ninety-six percent of the electricity output in Danish stationary power stations.

This dissertation uses as its leading category the groups of actors that engaged in, maintained or abandoned the different systems, and focuses upon their motives of choice. In doing so, it leans upon the work of the Dutch scholar Wiebe Bijker, as presented in his dissertation *The social construction of technology* (1990, 1995). In this perspective, the consolidation of decentral electricity supply systems as well as the ultimate success of centralization is seen to depend upon social processes and social inventions as well. In this sense, also the technical and economical success of centralized supply was a social as well as a technical construction. This dissertation, then, presents an empirical re-reading of the development of electricity supply in Denmark until 1970, which structures the study in a framework of co-existing rather than successive electricity supply technologies, and focuses upon the choices of the actors directly involved.

It should be mentioned that the case of electricity supply in Denmark is well suited for such an analysis. On one hand, the country is small enough to allow for a study of the piles of source material that follow the inclusion of a number of electricity supply systems and actors in parallel over a long period of time. And on the other hand, in Denmark small scale configurations of electricity supply seem to have been particularly successful at least until the 1950s, while by 1970 the victory of centralized supply over all others was complete and absolute. This was certainly not the case in all countries; in how far it was the case in leading countries as Germany and the United States remains, to my knowledge, to be investigated. Finally, the case of Denmark is well-suited to study the competition between central and decentral electricity supply systems, because the central government hardly intervened in the electricity supply business during the period under consideration, and, unlike in many other countries, did not one-sidedly support large scale electricity supply through legislative or economical support.

In this introductory chapter, a brief, selective and subjective reading of the historiography of electricity supply will serve to introduce the basic configurations of electricity supply at stake, and also the analytical framework of successive configurations of still larger scale. This reading will provide a point of departure for a more detailed argumentation for a recasting of this history in a framework of co-existing electricity supply configurations and a vocabulary, that centres around social dynamics.

A brief history of the scale increase in electricity supply

Four basic supply technologies and the logic of succession

In this study, the term 'configuration' or 'system' of electricity supply does not refer to one all-absorbing growing system defined by electrical linkages, but to a set of technologies which can function as an independent unit for electricity supply - even within a larger, all-absorbing system. International historiographies of electricity supply generally distinguish four such basic configurations or systems of electricity supply of increasing scale, which historically and logically succeeded each-other.[5] A first configuration of electricity supply relied on the first development of the necessary equipment - an electricity generator, wires and appliances - to make electricity supply available at a single site or in a single building. This included for instance electric lighting systems installed in French and English lighthouses from the mid nineteenth century, and electric light and also power systems installed in single factories from the 1870s. Following the terminology in European statistics, I shall retrospectively label this supply configuration with on-site electricity generation as 'autoproduction system'.[6]

Next comes the development of central station technology for supply of the local public in the early 1880s. This new configuration of electricity supply consisted of a central power station to generate electricity, and an external distribution network to transport the electricity to consumers in the immediate surroundings of the power station, including former autoproducers. It is important to notice the constraint of this supply system: Using direct current technology, which unlike alternating current does not allow for easy transformation of the voltage (see chapter four), these systems distributed electricity under low voltage suitable for consumption. As a result of this low voltage distribution, their economical supply distance was limited to at most a few kilometers from the power station (the relative power losses decrease with an increasing transport voltage[7]). Such systems, exemplified by the inner city systems that Thomas Edison's companies established in London and New York in 1882, are therefore commonly labelled 'local electricity supply systems'.

A third configuration of electricity supply arrived with high voltage, alternating current (and thereby low cost) electricity transmission around 1890. The new configuration included the concentration of electricity production in a much larger and favorably situated power station (for instance at the water site outside the town for cheap supply of coal and cooling water), the use of high voltage transmission networks to transport the electricity over an extended supply area, and local distribution networks which offered it as low voltage to the consumers. This supply form is illustrated by the famous power station built at Deptford, at the bank of the River Thames, to supply a large part of London by means of high voltage transmission from 1889, and which has been described as the "forerunner of all modern central power-stations."[8] To avoid terminological confusion, I will label this configuration of electricity supply, which may supply an entire urban or rural district, as a 'district electricity supply system.'[9]

Finally, a fourth configuration of electricity supply included the interconnection of different power stations into one power grid of very high voltage, and the further concentration of production in still larger and more economical power stations on the grid. In this final configuration, the electricity supply system could be organized at a regional or even national scale; such systems were first established during the First World War, and may be exemplified by the British national grid constructed in the 1920s and 1930s. In the present study, this type of system is termed 'centralized electricity supply.'

The logic of development in a framework of successive electricity supply systems, then, is obvious. On one hand, one system might expand according to this stage model. For instance, a local electricity supply system might expand to a district system by expanding its power station and adopting high voltage electricity transmission, and subsequently participate in a centralized system by interconnecting with other district systems and further expanding its power station. On the other hand, larger scale systems might absorb smaller scale systems: Local systems might take over supply to the previous autoproducers in their area, which then shut down their autoproducing plant. Likewise, district systems might start to supply previous local systems, which thereafter cease production and continue as distribution systems only, and finally centralized systems may absorb district systems in this way. In this process of scale increase the electrical network expanded, and electricity production was concentrated in fewer but larger power stations.

Scale increase in Denmark

A similar succession of still larger scale configurations of electricity supply can be discerned in the historiography of electricity supply in Denmark. Of course, historiographies differ in focus and inclusion of details, but the structure of succeeding systems is always visible, either in a technical perspective where these technologies logically followed upon each-other, or simply in a time perspective, in which different periods are characterized by new dominant technologies.

This mode of description arose already in accounts of the development of electricity supply by contemporary observers, who participated themselves in the electricity supply field. We may take, as an example, Valdemar Faaborg-Andersen's narrative of electricity supply in Denmark, which represented the history of electrification in an eight-volume work on Danish culture in the early 1940s.[10] Faaborg-Andersen was a first generation electrotechnical engineer educated in Denmark (1910), and working for the Electricity Council - a state institution registering and surveying electricity supply systems in Denmark - he was both a close observer and a participant in developments in electricity supply, since the Electricity Council mediated in negotiations between larger and smaller utilities on the supply by the former of the latter.[11]

Faaborg-Andersen's selection of events, which primarily make up the history of electricity supply in Denmark, includes the introduction of the four successive electricity supply systems and a brief mention of their decisive drawbacks, which facilitated the introduction of the next system. First, he briefly describes the 'official introduction of electric lighting' in the country in the form of an on-site installation providing an electric arc light demonstration at the riding ground of a Copenhagen

Palace in 1857. But it was only around 1880, when incandescent electric lamps became available for indoor electric lighting, that the first practical electric lighting systems were introduced in factories and larger stores. The disadvantage of this system, Faaborg-Andersen contended, was that each firm had to buy and run an entire system, and thus paid relatively high investment costs and maintenance expenses.

Implicitly regarding such autoproduction of electricity only as a forerunner of public electricity supply systems (that is, systems supplying the public, not necessarily owned by it), Faaborg-Andersen then deserts this type of system and shifts focus completely to the introduction of the local system. This happened in the early 1890s, beginning with the provincial towns of Køge and Odense in 1891 and in the capital Copenhagen in 1892. In the following decade a number of similar systems were established in larger provincial towns, and particularly after 1905 many smaller towns and villages followed. The problem of these systems, of course, was their limited supply area due to the low voltage transport of electricity. Early local systems operated with low voltages (defined as less than 250 volts between wires and earth) of 110 volts, and after the turn of the century they might use 220 volts. A technical improvement was the so-called three-wire system, which used three wires of 220 volts, 0 volts and -220 volts respectively: Light consumers could still be connected to receive 220 volts (between the mid and an outer wire), but the transport of electricity to central points near the consumers was made to occur through the two outer wires and thereby in effect by 440 volts.[12] With this technology, the supply area of the local system could be expanded from about one kilometer to some three kilometers distance from the power station. But the principal limitation remained.

Faaborg-Andersen marked the year 1907 as 'a turning point' ending 'the age of direct current' in Denmark. In this year, the municipal utility of Copenhagen and a private utility in Northern Zealand introduced district supply.[13] Their large power stations produced electricity at voltages of six and ten kilovolts respectively for transport over a much increased supply area. Here a number of transformer stations near the consumers reduced the high voltage to a low voltage suitable for consumption, and fed local, low voltage distribution networks which brought the electricity to the consumers. The focus of the account now shifts towards the diffusion of this system, which occurred rapidly in the large rural districts of the large islands of Zealand and Falster in East Denmark, while particularly in West Denmark local town systems were expanded to district systems to supply both the town, its outer districts and its hinterland. Within a few decades, high voltage networks covered most of the country.

Finally, Faaborg-Andersen addressed the ongoing centralization of electricity supply: The electric power plants of district systems were interconnected in a power grid of very high voltage, and electricity production further concentrated in few very large power stations. The economical advantage of this system was that large power stations could use their generation equipment more economically than many small power stations, and that they could co-operate on the power grid to share production capacity. This resulted in cheaper electricity for the consumer. Already in the 1920s such a power grid, with a transport tension of fifty kilovolts, had been established to cover most of Eastern Denmark, and in the first half of the 1930s the production of electricity was nearly completely centralized in two production sites only - a large power plant in Copenhagen and hydropower imports from Sweden. The following years the system was expanded with several new very large power plants to meet the rapid increase in electricity consumption. It was this development of centralized supply, that Faaborg-Andersen assumed would continue in the rest of the country in the following years.

Faaborg-Andersen thus structured his account according to a primary perspective of the succession of electricity supply systems, which ended with the large scale centralized system. He described the introduction of each system, but only until the next system was introduced. In other words, his focus was upon one technology for one period of time: Autoproduction systems were uninteresting after local systems were introduced; after 1907 the district systems are in focus; and from the 1920s the introduction of centralized supply is the dominant concern. Notably, Faaborg-Andersen's treatment of the subject is representative for all accounts written by involved observers from the 1930s to the early 1960s - the time when centralized supply grew to cover the entire country. To name some examples, this included accounts by Robert Henriksen (1939), Faaborg-Andersen's colleague at the Electricity Council, leader of its so-called co-operation committee and professor at the polytechnical school (now Denmark's technical university); several accounts by Aage Angelo (1943; 1945; 1953), director of one of the largest Danish electric utilities; and the jubilee publication of the Electricity Council (Elektricitetsrådet 1957).

Selection and explanation: Anomalies as social curiosities

There is, however, a secondary perspective, for which Faaborg-Andersen's account is also representative. Faaborg-Andersen could not avoid observing the remarkably slow diffusion of the newer and supposedly better electricity supply systems, and conversely that old, decentral systems did not disappear as rapidly as one would expect them to. Even after 1907 more local systems were established, and even after 1920 it proved particularly difficult to establish a centralized supply system in West Denmark, where local and district systems were constantly expanded. Faaborg-Andersen solves this anomaly not by challenging the claimed superiority of larger scale systems, but by a distinction between technically rational actors with technical and economic concerns, and technically irrational actors with social or political concerns. It were 'progressive technicians' or 'leading electrotechnical engineers', who rapidly 'realized' the advantages of larger scale supply systems and worked for their introduction in Denmark. But they met at times very strong opposition from other actors on the supply field, who maintained their decentral systems with 'irrational' arguments. For instance, the politically strong urban municipalities established their own systems instead of running larger systems together with neighboring towns, as they often were in a mutual competition. And in the countryside, each village or parish wanted to have its own local system, being afraid of dependence on and exploitation by towns in the matter of electricity supply. Faaborg-Andersen could observe that all 'attempts to convince direct current utilities of the advantages of alternating current supply were wasted', and attributed the consolidation of local systems to 'local-patriotic concerns'.[14] Finally, he made a similar argument with regard to autoproduction systems: As he observed in a contribution to a book on Denmark's industrial development (1943), the irrational 'thought of giving up independence with regard to power supply' could overrule economic rationality, and obstruct the 'natural choice' of purchasing electricity from an electric utility.[15]

Others also underlined the irrationality of decentral electricity supply in such terms: Professor Henriksen, for instance, found that "...the largest hindrance [for centralization] are the many local interests, which have arisen with local systems, and which for the large part are of purely sentimental character, against which all objective arguments are lost."[16] He also identified the will of rural utilities to maintain independence as 'separatism'. Given this fact, these observers also described remedies against this irrational obstruction of attempts to centralize electricity supply in Denmark. Therefore their narratives included events like the fuel shortages and government intervention during the Second World War, which motivated decentral actors to connect to larger systems. Technical progress (particularly large improvements in steam turbine production economy) should then make the centralized supply system decisively cheaper than supply by many smaller systems, and market mechanisms would do the rest.[17]

Explanation in historiography

Participating observers thus explained the succession of still larger scale systems with reference to a technical and economical rational line of progress. And like in international historiography, scholary work on the electrification process in Denmark generally adopts and refines a similar framework of analysis. One can start with the work of the contemporary economic geographer Steen Böcher (1945), whose geographical perspective led him to observe for instance the consolidation of large autoproduction plants and the many small rural plants. But he still adhered to the logic of a four stage model of increasingly rational systems, cited the 'bad economy' of a decentral electricity supply structure, noted that the continued existence of older systems defied 'warnings from technicians', and blamed separatist tendencies particularly in rural Denmark for this unfortunate development.[18]

The process of scale increase is also in focus in two analyses of the development of Danish electricity supply of the early 1980s. Winnie Kristensen & Kurt Olsen (1981) set out to 'demonstrate that the centralisation of electricity production was the result of an economic movement.'[19] In the course of their analysis, the subject matter is limited to East Denmark, and decentral systems are not included at all except for the very early period. The mechanisms of scale increase are then analysed in terms of economic competitiveness of different utilities and their systems. For instance, the subject of their treatment of the period 1907-1920 is the transition from local systems to district systems, which is on one hand explained by the limit on capital earnings following the limited supply area of local systems, and on the other hand by the economies of scale of larger boilers and turbogenerators.[20] And for the period 1920-1937 they study exclusively the strategies of the few very large utilities, which agreed to join forces in a centralized system, and describe the rationality of this step by the improved economy of production technology (including economizers and further improved boiler and turbogenerator designs) of the large Copenhagen power station, which resulted in low running costs.[21]

Also Jørgen Rasmussen (1982) shares this concern for centralisation, but focuses upon the organisational centralisation, which for him was a kind of forerunner to the concentration of business and social life in general during the transformation from a decentrally organized, agricultural society to a centralised, urban and industrial society.[22] He sees organisational centralisation as a necessity for capital intensive sectors, through which large companies could concentrate technical and economical resources and exert political influence. He also noted the bureaucratisation in such companies as a strategy to preserve their position, a part of what Hughes (1983, 1987) called the 'momentum' of large sociotechnical systems. Although Rasmussen does observe a continued expansion of town and village systems, he takes the overall view that small companies might present a social and psychological advantage to the employees, but also proved economically irrational in a capitalist society.[23]

Supplementing these analyses with a large, narrative, cultural history of public electricity supply, Birgitte Wistoft et. al. (1991-1992) do take a different view than the strictly economical one. Certainly also this work focuses mainly upon the new systems of each time period, but as it aims at constructing a broad view using source material from many large and small utilities, it does to some degree bring in the consolidation of decentral systems (excluding autoproduction systems) by presenting perspectives from small utilities on the development process. Being a narrative history it does not pursue this issue into a thorough analysis, however, and it does not challenge the basic assumption of the apriori economical superiority of large scale supply systems.[24]

Finally, the development of electricity supply in Denmark has most recently been analysed by the Swedish scholar Arne Kaijser (1995) in a comparison with developments in the other Nordic countries Norway, Sweden and Finland. Like the earlier Danish analyses, also this study is exclusively concerned with the process of scale increase, in this case the expansion of the electrical networks, which is explicitly formulated in a three phase model of scale increase. And also this study focuses upon economic incentives for this scale increase, which could differ in the different countries mainly due to different geographical preconditions: Norway, Sweden and Finland possessed rich but differently distributed hydropower resources, while Denmark - at no point higher than two hundred metres - largely lacked such hydropower resources. For instance, it observes that the economic incentive for the step from local systems to district systems (in the terminology of this dissertation) in Norway, Sweden and Finland was to obtain 'economies of substitution', that is, substitution of thermal power plants with hydro power plants to decrease the production costs, while in Denmark it was to obtain economies of scale. But although incentives might differ, also this study takes the economic advantages of scale increase for granted: For instance, following the Danish historiography of electricity supply (which is its sole source for the Danish part of the study) it assumes that district systems in Denmark in fact could supply electricity to local systems "cheaper than the power they produced themselves", and cites the strive for 'independence' by rural utilities as the reason for the relatively slow diffusion of this supply system.[25]

The argument

Perhaps with the exception of purely narrative histories, one may thus read a convergence in the international and the Danish historiography of electricity supply on a description in terms of a succession of still larger scale electricity supply systems, and on an explanation of this development in terms of an increasing technical-economical performance - whether this follows from more economical production technology, scale advantages, load factors, economic mixes, more resourceful organisational constructions or a combination of all these factors. Anomalies in this pattern, such as the continued existence of decentral electricity supply systems after the introduction of new, larger scale systems, are often explained by a social rather than technical or economical logic, if explained at all.

I have emphasised these aspects in my reading, as they are a point of departure for a well-known critique in technology studies. For although the focus upon increasing successes is justifiable, because its key events were important and deserve the focus of attention, its accompanying historiographical problems were early recognized. Already in the late 1950s, Howard Jones observed how an emerging history of technology, which not yet had reflected upon its own philosophy, used a framework of 'a straight-line narrative of increasing success' to organize its primary material. Yet Jones knew from his own field of philosophy and literature, that a great production might 'be hidden or undervalued for decades ... and yet take on primary importance for understanding man.'[26] In the same way, in the history of technology - also a way of 'understanding man' - the linear model of increasing success might obscure important technologies of the past. Indeed, already Jones called for a 'history of failure' to compensate for the bias of the linear model, and provide a more nuanced understanding of the mechanisms of progress.

The point has been made several times since then.[27] It was also presented in greater detail by Bijker (1990), for whom it provided a point of departure to formulate an alternative analytical framework, which will be used in this dissertation. According to Bijker, the linear model leads students of technology to the 'pitfall of retrospective distortion': The history is distorted because a teleology is retrospectively read into the historical material. One may understand this retrospective distortion to work at two levels.

First, at the level of description, it causes the student to marginalize technologies that in retrospect are characterized as unsuccessful: As they are currently unsuccessful and have been replaced by newer technologies, it is assumed that this was so from the moment that the new technology arrived. Taken to its extreme, the linear model describes the development of a technology only until a successor arrives; hereafter the former is considered a 'forerunner' of the latter, which then claims the focus of the narrative. In a 'soft' version, this model may incidentally observe the continued existence of 'older' technologies side by side with the new one, as in the case of electricity supply, but still lacks their structural inclusion in the description. This mechanism is for instance well known from studies of the industrial revolution: Concerned with the introduction of mass production, these tend to neglect the fate of older, small scale production systems. In some cases this proved to be historically correct, but in other cases it was later proved wrong.[28]

Second, at the level of explanation, the historical development is retrospectively provided with a technical rationality: It is assumed that the currently dominant technology must be technically the best one (otherwise it would not have been such a success), and this technical superiority is extrapolated back in time. As Bijker and also Jones noticed, this assumption is invalid and makes the explanation tautological:

The (current) success of an artifact is adopted as the explanatory ground for its (historical) success. Progress becomes its own explanation.

Borrowing from the sociology of scientific knowledge, Pinch and Bijker (1984) coined this mechanism as the 'asymmetrical explanation'. In the so-called 'strong programme' in the sociology of scientific knowledge, an asymmetrical explanation referred to the explanation of the success of a scientific theory currently accepted as true and the success of a theory currently considered false in different categories, the former in terms of its truth (e.g. in terms of correspondence with Nature), the latter typically in terms of social or political circumstances. Instead, it was argued, the analyst should be impartial to the truth or falsity of the theory, and explain both cases symmetrically in similar categories, that is, in terms of social logic. In a corresponding argument for the case of machines, Pinch & Bijker argued that the analyst should be impartial to the technical superiority of the technology (in terms of 'working' or 'not working' of artefacts). An asymmetrical explanation would explain the success of the new technology (currently considered technically superior) and the possible success of the old technology (currently considered inferior) in different terms: The success of the former would be explained with reference to technical factors, the success of the latter typically with reference to social factors. And, conversely, the failure of the old technology may be explained in technical factors, while the failure of the new technology in another time or space is attributed to social factors (as 'being ahead of its time'). It is the asymmetrical explanation, that makes technical progress explain itself, and avoids the interesting question how the successful technology 'came to be seen as' the technologically superior technology.[29]

To avoid both pitfalls, Bijker suggested to replace the linear framework as a whole by a framework of analysis, which strategically treats technologies as co-existing and treats them symmetrically - in casu through the conception of social groups (see below), which leads to the formulation of the model known as SCOT (the Social Construction Of Technology). In this way, also the retrospectively unsuccessful technologies are described, and an inclination towards teleology is avoided. One may ask if this is necessary; one can also imagine a more or less linear framework with a widened narrative, which leaves room to include at least some diverging technological options. But there is little doubt that an alternative framework of co-existing technologies, which is developed for this purpose explicitly, has the strategical advantage. This may be particularly important in the case of electricity supply, the systemic character of which makes the linear model of system expansion particularly seductive - which is probably why this well known critique has not been applied to this field. And as also Michael Hård (1993) has noted, even the well known theory of expanding sociotechnical systems easily assumes an uncritical functionalist shape.

Under all circumstances, transferred to the specific field of electricity supply in Denmark, one may adopt Bijker's general critique by replacing the notion of technological superiority by a technical-economical one, and by expanding its range not only to a short time period of invention and innovation, but to the diffusion and consolidation of electricity supply systems in society over half a century or more. The necessary concepts will be further addressed below. Suffice it to say here, that the diffusion and consolidation of decentral electricity supply systems is currently underexposed, and that an asymmetrical explanation prevails: For in this particular field, as observed above, larger scale systems are given an intrinsic economical superiority, and the possible continued existence of decentral systems is explained with reference to motives like the drive for autonomy, local patriotism and separatism, in short a socially or politically motivated resistance towards an economically rational change.[30] But as we shall see, this is merely echoing the rhetoric of one of the actor groups - the most visible one to be sure - in the field of electricity supply, while others strongly disagreed for most of the period under consideration. A symmetrical framework exposes this aspect.

Readdressing Danish electrification: A statistical survey

The importance of this matter may best be illustrated with a statistical analysis, which shows the absolute as well as the relative dynamics of the decentral and central electricity supply systems at stake. How important were decentral electricity systems in fact in the period under consideration? Indeed, the available electricity supply statistics allow for a rough quantitative assessment of the reductionism of the linear framework for selecting events for the Danish case. It is possible to describe the dynamics of each of the four basic electricity supply systems introduced above in terms of their number and electricity output from 1910 to 1970, the end year of this investigation, when centralized electricity supply dominated the scene completely.

Still, such an analysis involves several problems. The first concerns the adaptation of the demarcation criteria of the four systems, so that each can be included in the entire period under consideration. For in this analysis, 'old' systems are allowed to use technologies belonging to a 'later stage' in the linear framework, as long as their decentralized production is maintained and they principally maintain their original character of decentral production systems. For instance, autoproducers were above demarcated from public supply systems as on-site generation systems without an external distribution network, what the Swedish economic geographer Filip Hjulström (1940) called 'points' according to their geographical picture.[31] However, an autoproducing factory that co-exists with a public supply system may well use the 'new' technological option of (inter)connecting to this system, for instance in order to buy small amounts of electricity for lighting on Sundays and holidays, when its own engines are shut down. This factory may function unchanged as an autoproducer for most of the time, and thus use the connection in a peripheral way. Likewise, an autoproducer may use such a connection to sell surplus energy to an electric utility, or merely to increase the security of supply by using the public system as a back-up to its own production system. As long as its consumption of autoproduced electricity is much larger than its possible sales to a utility, from a production point of view the autoproducer remains primarily an autoproducer, which is not very different from autoproducers that exist in complete isolation from any electric network.

A similar point may be made with regard to local systems, defined by their production and distribution of electricity of low voltage only, and district systems, defined as single power plants (as opposed to centralized systems) using high voltage electricity transmission (as opposed to local systems). Also these kinds of systems may connect to larger systems for instance to purchase additional electricity, and thereby postpone an investment in new production machinery. In addition, they may even be directly interconnected in the power grid of a centralized system, which is defined by (1) the concentration of production in very large power plants and (2) their interconnection in a grid. Systems remain decentral local or district systems despite such (inter)connection, however, as far as they structurally maintain electricity production in relatively small power stations (that is, not only to carry the peak load), instead of shutting them down and concentrate electricity production in the large plants on the grid. The electricity they purchase is, of course, included in the larger production systems.

In sum, in this study it is the production and mode of transport from power station to place of consumption that defines the system, even though the system might in fact exploit a connection to a larger system. This demarcation is of course a choice of interpretation. In a linear framework, any connection would be interpreted from the point of view of the larger system, for it is exactly the expansion of the network that is the subject of investigation. Not so in this study, where a local village system in complete isolation and a local village system with decentral production but a back-up line to a larger system are included in the same category: For it is such demarcation that enables the study of why decentral production was maintained in the group of village systems in the first place, regardless of their relation to the rest of the electrical world.

A second problem is the practical application of the demarcation criteria on the available electricity supply statistics. To start with, until the early 1950s these statistics list electricity supply companies rather than systems. However, only few companies in fact operated more than one system, so the error is marginal - perhaps with the exception of the error induced by the municipal utility of Copenhagen, which joined the centralized system at an early stage, but later reopened old decentral power plants for combined heat and power production in the inner city, which due to the large concentration of inhabitants in fact were quite large systems. They were small, however, relative to the production in the main Copenhagen power station feeding the centralized system. In addition, the electricity supply statistics operate with categories different from the ones used in this study, and the demarcation criteria even change in time. In the early 1950s, even the basic categories themselves were shifted out. Together with the fact that some systems used the available technologies quite creatively in all kinds of combinations, the reinterpretation of the statistics often demands an individual assessment of single or groups of systems. Due to the uncertainties involved, the tables below primarily present orders of magnitude.

Table 1.1: Approximate number of basic electricity supply systems for selected years 1910-1970.[32]

	1910	1923	1931	1939	1950	1960	1970
Autoproducers*	796	-	1600	1500	2100	2000	2000
Local systems	233	429	411	386	284	93**	7
District systems	8	44	44	47	44	24**	14
Centralized systems	0	2	3	3	2	2	2

* The figures for 1931, 1939, 1950, 1960 and 1970 are rounded off.
** The electricity supply statistics do not include information on the mode of electricity production in very small systems, and as a minority of local systems may have adopted means for high voltage transmission of *decentrally produced electricity*, the number of local systems might be slightly overestimated and that of district systems underestimated.

Table 1.2: Approximate net outputs of the four basic electricity supply systems in Gigawatt hours for selected years 1923-1970.[33]

	1923	1931	1939	1950	1960	1970
Autoproduction systems*	85	240	303	313	393	427
Local systems	33	46	65	95	38**	0
District systems	170	151	248	303	179**	279
Centralized systems	39	261	491	1.640	4.343	17.067

* Results of a census among large autoproducers. As the majority of autoproducers is excluded, the figures underestimate the true output.
** As in table 1.1.

What, then, does such a reassessment of the statistics learn? First, the dynamics of each configuration of electricity supply taken individually, it reveals that even though centralized supply had been introduced by 1920, decentral systems were consolidated and often expanded in an absolute sense at least until the 1950s. This is most clear for the system of autoproduction of electricity. This system is not addressed in the Danish historiography of electricity supply after 1890, when public supply systems became available. As already contemporary observers supposed, from now on these systems were bound to disappear. However, the contrary was true. In the mid 1880s, there may have been around fifty autoproduction systems (see chapter 2). By 1910 this number had increased to some eight hundred, and although the country was now rapidly covered by high voltage networks supplying energy from larger scale systems, by the early 1930s this number had doubled. In fact, it only topped around 1950, whereafter it did not decrease, but stabilize in the following decades. And in terms of output, the system of autoproduction grew during the entire period under consideration and continues to do so today.

With regard to local electricity supply systems, also their number rapidly increased after district systems were introduced in 1907. In fact it almost doubled between 1910 and 1923. Hereafter it stabilized, with a small decrease before the Second World War, and a larger decrease during the 1940s. However, by 1950 there were still nearly three hundred of such systems left. Only during the 1950s and 1960s, nearly all these systems disappeared with the exception of a handful of systems, which were situated on small Danish islands. And in terms of output, the local system grew until the 1950s, whereafter it declined rapidly.

Contrary to autoproduction and local systems, the number of district electricity supply systems did not increase significantly after the newer, larger scale technology of centralized supply had been introduced around 1920. On the other hand, the number did not decrease either until the 1950s. Then it gradually fell, so that by 1970 only a particular group of small hydropower systems remained. In terms of output, however, the district supply system grew rapidly for most of the period under consideration; there were some decreases, but these might result from the absorption of some large district systems in centralized systems (such as the large Copenhagen system in the mid 1920s). Finally, with regard to the centralized system, there is nothing but growth: Two such systems came to cover East Denmark and West Denmark respectively, and particularly in the post war period their output exploded. A first conclusion, then, is that despite the immediate success of new, larger scale electricity supply systems, the older systems continued to expand at least until the 1950s.

Second, the tables also show the importance of the different electricity supply systems relative to each other. In terms of numbers, of course, decentral systems constituted and still constitute the large majority of systems. And in terms of output, it comes as no surprise that the importance of centralized electricity supply (including imports) increased since its first introduction, from about twelve percent in 1923, via forty-four percent at the eve of the Second World War, to seventy percent in 1950 and ninety-six percent by 1970. This system was indeed a huge success. But it should also be noted, that by the eve of the Second World War - some twenty years after the introduction of the first centralized supply systems and the rhetoric elevation of this system as the economically superior one (see chapter 5) - it only accounted for less than half of the electricity output by Danish electricity supply systems. A study, which excludes decentral production systems from its analysis, thus not only lacks the large majority of systems, but also most of the electricity produced. By 1950 decentral systems still produced some thirty percent of the electricity output, and only during the 1950s and 1960s their importance became marginal, their output being reduced to four percent by 1970. A second conclusion, therefore, is that the linear framework obscures parts of the electricity supply structure in Denmark, which had considerable importance until at least the 1950s, but thereafter rapidly lost importance.

Project design

Actor groups and related concepts

In a view of co-existing systems, then, one can point at two important developments in the history of Danish electricity supply until 1970. First, the underexposed consolidation of decentral systems until the 1950s. And second, the giant success of centralized supply during the 1950s and 1960s. These two issues structure this dissertation.

In addition to the framework of co-existing systems, this dissertation also seeks to take serious the demand of symmetrical analysis as defined by Pinch & Bijker. This means on one hand, that it investigates (and rejects) the asymmetrical attribution of technical-economical rationality to large-scale systems and possibly a social or political rationality to smaller-scale systems, as is customary in much historiography of electricity supply as described above. Therefore, it aims to be particularly sensitive to claims of technical or economical superiority by representatives of small scale systems, while it tries to by particularly sensitive also to the social logic of centralization. Notably, this reverse of focus is merely strategical, and does certainly not imply that small scale systems in fact were technically or economically more rational than large scale systems: It only supplements the well-known claims of technical-economical superiority by representatives of large scale systems and their attribution to social logic of consolidation of small scale systems. The point is that representatives of all systems could claim technical and economic rationality of their choices.

On the other hand, it operates with only one vocabulary to structure the dynamics of all systems involved. This vocabulary draws upon the work of Bijker, who for the process of invention formulated a number of concepts allowing for a social understanding of the construction of artefacts in their formative stages. Several concepts can be fruitfully adapted for the case of the diffusion, consolidation and centralization in electricity supply. To start with, the leading concept in this dissertation is that of the *actor group*, understood as a homogeneous group of actors that engaged in electricity supply. Such actor groups in fact presided over the different electricity supply systems, and their choice between having their own system or purchasing electricity from elsewhere resulted in the dynamics of each electricity supply system. The concept is a variation on Bijker's *relevant social group*, which is a broader concept, including for instance manufacturers of artefacts and different groups of consumers.[34] Yet this concept was developed to investigate the early development of consumer products, and sought to involve as many social groups as possible which had a certain expectation (in Bijker's terminology: interpretation) of the actefact and therefore drew its function and shape in a certain direction. The problem of such a strategy, of course, is to find all relevant social groups which have an opinion on an artefact, and a well known critique is that the analyst is prone to miss weak groups and thereby may reproduce past power structures.

The focus of this dissertation, however, is much more narrow. It primarily wants to investigate the dynamics of different supply systems, and with this end in view it narrows down the specter of relevant social groups to those which actually engaged in a form of electricity supply, and became dominant actors on the electricity supply market. It is the choice of such actor groups to engage, maintain or abolish a particular electricity supply system, that is the focus of this investigation. It is not difficult to find which groups are relevant: This follows from the recordings of ownership of different systems, for instance in the electricity supply statistics. The very large majority of local systems, for instance, were run by merely two actor groups of municipalities and rural co-operatives between 1910 and 1970. Certainly there were smaller actor groups, which largely are left out of consideration in this study. For instance, electrotechnical manufacturers establishing their own utilities - a successful practice in the United States - are only included briefly in the process of initial introduction of local systems, but are then excluded as a marginal group with no importance for the further dynamics of this system - its diffusion, consolidation and also its decline. Likewise, other social groups such as that of consumers did not act directly on the electricity supply market. Most utilities did simply 'black-box' this group to an independent variable of increasing electricity demand, which the utilities had to meet (even though utilities in fact tried to influence this variable via advertizing etc.). This study accepts such black-boxing; it was only in the cases of autoproducers and co-operatively owned utilities, that the consumers had a direct influence, in the former case because they were identical with the producer, and in the second case because they directly owned and had decisive power of the utility. But this also means that as their concerns turn up in an actor group perspective, a separate group of 'consumers' is not required in the investigation.

The question then is what defines an actor group. This study regards an actor group as a group of actors acting on the supply field with homogeneous concerns, which result in a significant correspondence between the concerns of the group at large and the choice of supply system of the single group member. Particularly useful entries for such group concerns are spokespersons - nearly always spokesmen - speaking on behalf of a group, interest organisations established to protect the interests of a group, and journals in which members discuss their preferences. An example of such a spokesman is Vilhelm Mondrup, chairman of the Danish and Jutland associations of rural utilities, the members of which exploited small local systems on the countryside. In his annual addresses to his Jutland association, he treated in general terms the arguments for a continued decentral production versus the shut down of the decentral rural power stations and purchase of electricity instead. Such addresses are an example of texts, from which a (changing) discourse on rural local systems can be read, and which can be supplemented by case studies of individual rural utilities to examine the dynamics of this large group of systems. In some cases, however, the actor groups are too small for organisations, journals and visible spokespersons: The actor group of cement factories, for instance, was an important group for the consolidation of autoproduction systems (in terms of electricity output), but included less than ten factories, which were dominated by a cartel. They did not communicate via journals, and their choices must be studied through the descriptions of other observers (such as utility representatives) and decisions in the individual factories.

A concept relating to that of homogeneous actor groups is that of *inclusion*. Bijker uses the concept of degrees of inclusion to make the adherence of individuals to several technological frames (a kind of paradigm) flexible. Instead of being part of such a frame or not, they could have different degrees of inclusion in different frames. This dissertation uses the concept of inclusion to make flexible the relation between actor groups and their members. For instance, some large municipal utilities and large rural utilities advocated centralized supply, and thereby came into conflict with the majority of municipal utilities and rural utilities respectively. As a result, these had a low inclusion in the actor group (and technological frame) of the municipal and rural utilities respectively, while other - typically smaller - utilities may have had a large inclusion. Instead, these few large utilities formed their own 'actor group of very large utilities', in which they had a high inclusion, and which dominated the public debate and government committees with its discourse of centralized supply.

Finally, a concept worth mentioning is that of *closure*. Bijker uses the term, also used in science studies, to describe the stabilization of an artefact in terms of the increasing convergence of meanings attributed to it by relevant social groups. Such closure can be achieved in various ways - rhetorically, for instance.[35] The interesting point is that after such a closure, a broad agreement or consensus is reached as to which technical shape, or scientific theory, is the best one; this superiority is turned into a fact, which afterwards it will be difficult to challenge. In the case of electricity supply, during the 1950s and 1960s most actor groups adopted the view that centralized electricity supply was a technical and economical necessity. Simultaneously, they began to redefine the historical development of electricity supply in terms of a linear model with a technical and economical rationality. For instance, in 1953 the municipal treasurer of the small town of Skive in Jutland, C. O. Barsøe Sørensen, in an address to a meeting of municipal treasurers observed that "technical and economic factors condition electricity production in large common power stations", and that "the concentration in large power plants must be seen as an expression of the fact, that the technical developments in electricity supply have blown up the existing municipal borders."[36] This argument had been expressed by propagators of large scale supply since the first decade of the twentieth century. But it was new for representatives of smaller urban municipalities like Sørensen's: For half a century, the actor group of municipal utilities had strongly disagreed with this view, and in fact the municipal utility of Skive had chosen decentral expansion several times, even years after it had been interconnected in one of the first truly large scale systems in Denmark (the Gudenaa -Århus co-operation in Mid-Jutland, see chapter 5). What happened in the post war period was, that municipal utilities were in a process of reaching consensus with their former opponents, the very large utilities, on the conditions for joining centralized supply. And once this consensus was accomplished and implemented, they too described this process - the rationality of which they had previously contested - as the most natural thing in the world, and it became difficult to imagine that things could have been different. The notion of a closure process thus allows historical discourse both to re-open the heterogenity in the development process before closure, and to decribe the process of closure itself as an important part of the final stages of this development.

Final remarks

This dissertation, then, seeks to re-open the development of electricity supply in Denmark, which had resulted in the overwhelming success of centralized electricity supply by the 1960s. It provides an empirical study of the dynamics of four configurations of electricity, studied through the actor groups that maintained them.

Part I discusses the introduction and diffusion of the four electricity supply systems in Denmark. All chapters are built up similarly: With regard to the introduction of each system, the process starts with the invention of the system abroad, its actualization (the introduction of an idea) in Denmark, and the initiative by few actors to actually introduce it (the introduction of the technology). But it is the *diffusion* of the system in Danish society, that made it of structural importance. Here, it is first investigated which actor groups engaged in the diffusion of the systems, and then the motives and concerns of this actor group are studied in detail.

Part II aims at investigating the consolidation of the three decentral configurations of electricity supply, after centralized supply had been successfully introduced and certainly had become the dominant paradigm in leading engineering and government circles. To this goal it departs not from the individual systems, but describes the consolidation of decentral systems from the point of view of the relevant actor groups for decentral systems: Autoproducers (which again were a range of smaller actor groups such as cement factories and farmers), municipal utilities and rural utilities. For these actor groups might exploit several systems; municipal utilities, for instance, exploited both local and decentral systems, often dependent upon the size of the town, but jointly turned against further centralization to preserve the decentral town systems. The strategy is to start out by seeking for a characteristic discourse on electricity supply for the actor group concerned, which then is supplemented by studies of individual cases. And as mentioned above, this part aims to be particularly sensitive to claims of technical and economical superiority of decentral systems, and conversely to attributions of irrationality to centralized supply.

Part III decribes the process of centralization likewise from the point of view of these actor groups, with focus upon the role of social mechanisms in the technological closure process. Also here a reading of a common discourse is combined with a study of concrete cases. It ends with the situation in the 1960s, when the consensus on centralization was stronger than ever before - and after. Visions of further scale increase included the (never realized) introduction of very large scale nuclear power plants, and the (realized) connection to Norwegian hydropower plants for large scale hydropower imports. Since then the situation changed again, and decentral electricity supply has increasing interest today, perhaps in particular in Denmark with its wind turbine industry and expanded district heating systems, which make combined heat and power plants attractive also in smaller towns.

The focus upon the dynamics of four basic configurations of electricity supply and their actor groups, finally, also implies that several issues do not get much attention. On one hand, this includes such issues as the meaning of electricity for consumers and society at large, the kind of issues Nye took up for the United States. On the other hand, more remarkable perhaps for a study in technological history, it does not dive into the technologies that constituted the four basic electricity supply systems. For instance, it does not deal with the invention and production of primary engines, generators, electric wires and so on to any great extent. Neither the development efforts with regard to for instance atomic power or wind turbines are in focus. These issues are decribed well elsewhere.[37] In this dissertation, such technologies are included only to the extent that they have direct importance for the dynamics of the basic supply systems which they constitute. Otherwise, the availability of the necessary technology to make each system work is largely taken for granted.

With regard to this availability, two remarks are in place. The first is that Denmark is not normally considered as a forerunner in the field of electricity supply. Most important inventions were made abroad in such countries as the United States, Germany, Switzerland or Sweden. Still, the necessary machinery was available in Denmark: In this respect it is important that Denmark neighbours two countries, Germany and Sweden, the electrotechnical industries of which moved on the front of technical development, and had sales departments in Denmark. In addition, the production of most machinery was also taken up by Danish producers. For instance, already from 1881 a Danish type of electricity generator was in production (and received a gold medal in the Paris international electricity exhibition), and during the 1880s and 1890s Danish producers brought generators, motors, accumulators, electric wires, etc. on the market.[38]

In addition, it is important to notice that technological development not only supported large scale technology. Certainly, the capacity and efficiency of boilers, turbogenerators and high voltage wires was continuously improved, particularly by efforts in foreign electrotechnical industries. For instance, large companies as the General Electric Company and the Westinghouse Electric Corporation in the United States produced single turbogenerators with a capacity of more than twenty megawatts before the First World War, twice the capacity of Denmarks largest utility in Copenhagen - which used more than twenty generators to achieve it. Likewise, they produced transmission systems for a hundred and fifty kilovolts by 1914, when the maximum voltage in Denmark remained ten kilovolts.[39] In this respect, Denmark was a follower. But on the other hand it was the Danish machine factory Burmeister & Wain, which improved the diesel engine design for the market of ships and also smaller electric power stations, which meant that also for small scale systems an economical engine was available. Likewise, it is well-known that is was in Denmark, that windmills were successfully adapted to produce electricity in very small scale systems. In sum, actor groups exploiting small as well as large systems could benefit from technological advances available from foreign as well as national or regional producers.

Part I

The introduction and diffusion of four configurations of electricity supply

2
Autoproduction systems

Developments abroad

The earliest form of electricity supply, that of autoproduction, presupposed as a minimum the availability of equipment to produce and use electricity in practical purposes. Such equipment was developed during most of the nineteenth century, resulting certainly by the 1870s in commercially feasible autoproduction systems for electricity supply.[1] With regard to apparatus to produce electricity, prior to the nineteenth century frictional machines were used to produce static electricity. Yet their discharge was difficult to control, and their use remained largely limited to the scientific laboratory for work in electrochemistry and electrostatics. A new source of electricity was added around 1800, when Alessandro Volta demonstrated that electricity could be produced chemically in his voltaic pile, which was soon improved into a usable battery. Contrary to the static electricity of frictional machines, batteries produced 'dynamic' electricity - a steady flow of electric current. Finally, from the 1830s mechanical generators of electricity were developed and improved, which had a significantly higher output of dynamic electricity than batteries. Such generators became the most important technology of electricity production in heavy current electricity supply systems (as opposed to low current systems, including e.g. telecommunication systems), where batteries might be included for storage or back-up purposes. They used the principle of magneto-electric induction demonstrated by Michael Faraday in 1831, that is, a changing magnetic field induces an electric current in a coil of wire. Mechanical generators therefore consist of a magnetic field system and a system of coils, in which the generation takes place; to achieve a changing magnetic field in the coils, either the magnets or the coils were mechanically revolved, while the other part was fixed. Such generators had been build from 1832, and their capacity was since scaled up by for instance increasing the amount of coils, by replacing permanent magnets with electromagnets, and by replacing manual rotation with drive by a steam engine. Contrary to the unidirectional or direct current of the battery, early generators produced alternating current, which could be turned into a unidirectional (yet pulsating) current by means of a so-called commutator (a device alternatingly shifting the direction of the current). Yet Zénobile Gramme's famous generator of 1870 produced a rather steady direct current, and since then both alternating and direct current generators were continuously further improved.

Of heavy current applications, electric lighting was clearly the most important one during most of the nineteenth century. Until the 1880s, electric lighting was primarily produced by arc lamps: Already in 1802 Humphry Davy had produced a continuous clear and white electric 'spark' between the poles of a battery by using carbon instead of metal poles. With the procuration of a purer and harder carbon and means to automatically maintain a constant distance between the carbon poles as they were consumed, from the mid 1840s electric arc lamps were sufficiently developed for public demonstrations, and since continuously improved for practical purposes (see below). A second lamp type, the incandescent lamp, was not developed in a practical form before the late 1870s. In this lamp, an electric current flows through a filament and thereby causes the filament to glow, thereby producing a light much weaker than the very bright arc light. During the first half of the century, incandescent lamps with platina or carbon filaments placed in a glass bulb vacuum (to prevent quick oxidation of the filament) had a very short life time, partly due to an imperfection of the vacuum. Using a new type of high vacuum pump, Joseph Swan in Great Britain as well as Thomas Edison in the United States managed to produce durable incandescent carbon-filament lamps in the late 1870s. Electric incandescent lamps were then put in mass production, and important later improvements included new metal filaments of tantalum (1905) and tungsten (1908).

Another crucial application of electricity is to provide power. In electric motors, the principle was the reversed of the dynamo - to produce a magnetic field from an electric current and thereby produce mechanical motion. Yet although experimentary electric motors existed, their production for practical purposes was first taken up in the 1870s in the form of a reversed Gramme generator (1873), a direct current motor seriously considered for industrial use. Different types of alternating current motors were first developed from around 1890, and it was not until the twentieth century that motive power became a major application of electricity supply.

Connected by electricity conducting copper wires, these elements for producing and using electricity constituted the first commercial autoproduction systems around the mid nineteenth century. Battery powered arc lights had been used for lighting demonstrations, but by the late 1850s batteries were substituted for steam powered generators to produce a commercial arc lighting autoproduction systems, used in Great Britain and France particularly to improve lighthouse illumination. Particularly since the demonstrations of Gramme's dynamo in Paris in the early 1870s, the general interest in electric lighting increased, and the uses of electric arc lighting expanded. In France, autoproduction systems for arc lighting were introduced in several factories, including a mill in Mulhouse, which used four Gramme dynamos to power four arc lights in 1875. The same year a chocolate factory, rubber factory and cotton mill followed. And the year after, a French railway company installed the first autoproduction system to illuminate a railway station. From then autoproduction systems were introduced for electric arc lighting also in Great Britain and in the

United States, not in the least to provide street lighting.

In addition, also practical electric power systems were introduced in the 1870s. Already at a 1873 exhibition in Vienna the Gramme company had demonstrated a system, in which a generator powered an electric motor, which in turn drove a pump. The year after the company installed electric drive in its factory in Paris, and started selling electric power installations to other factories. And in Germany, the Siemens company actively developed electric drive for application in the mining industry on request of the Prussian State Mines in the late 1870s and early 1880s. This included electropowered drills as well as electric railway locomotives; the latter technology was first shown at the Berlin Trade Exhibition in 1879, and in practical operation in a mine in Saxony by 1882.[2]

From then, the number of autoproduction systems rapidly increased, not in the least thanks to the availability of electric incandescent lamps, which were much weaker than arc lights and thereby allowed for electric lighting indoors. Already by the mid 1880s there had been established more than four hundred electric lighting systems in the United States and more than a thousand in France. Ninety percent of the French systems was situated in factories or work shops, while also a number of theatres, ships, private houses and shops had such installations. Together, the French systems supplied about six thousand arc lamps and more than fifty-five thousand incandescent lamps.[3]

Autoproduction systems in the Danish technical press in the 1870s

Before autoproduction systems for electricity supply were actually introduced for practical purposes in Denmark, they were introduced for a reading audience in the popular as well as the technical press. While in the 1860s notices of electricity had mostly concerned the electric telegraph, from the 1870s journals of industrial associations, the journal for physics and chemistry and from the late 1870s also in that of the new Technical Society [*Den Tekniske Forening*] occasionally addressed the phenomenon of electric lighting. In 1874, for instance, the industrial journal *Industri-Tidenden* described the advantages of electric lighting as the 'most intensive artificial light yet known.'[4] The journal also referred its practical use abroad, particularly in lighthouses, and described the working of the new Gramme dynamo. Focusing more upon the applications, one year later it observed that electric arc lighting had proved valuable abroad in industrial, military, scientific and public contexts. The former included illumination of nightly labour for instance at construction sites, the latter included the lighting of public streets, theatres and lighthouses. The results had mostly been satisfactory, but in some systems there had been many interruptions. A large development effort, however, had resulted in the 'nearly complete' solvation of such problems for the most modern lighting equipment. In addition to this technical progress, it observed that the latest development efforts had facilitated a huge increase in intensity. Technically, lighthouse projectors could produce a light which could be seen at more than forty kilometres distance, while military arc lamp projectors could explore enemy lines up to several kilometres distance, as repeatedly demonstrated by the French in the French-Prussian war.

In the following years, the technical press communicated the important events in the international history of electric lighting to the Danish audience, including the technically and economically satisfying electric arc lighting system of the Mullhouse mill, the commercial activities of the Gramme company and the development of the 'Jablochkoff arc light', a practical and popular lamp type which was rapidly adopted. By 1878, the issue of electric lighting was also addressed in broadly oriented weekly magazine *Illustreret Tidende*. Its editors had invited director Bernhard Olsen of the Copenhagen Tivoli to write on this matter, as he had recently tested electric arc lighting in the Tivoli.[5] Olsen pointed at the great intensity of electric arc lighting as both an advantage and a disadvantage: On one hand, electric street lighting in London showed that some twenty arc lamps could replace some hundred gas lamps and provide strong illumination. But as the tests at the Tivoli demonstrated, unless the arc lamps were situated in high places, the great intensity also tired the eyes and scared people away. Quoting an 'expert' on the issue, Olsen introduced the distinction between 'luxury purposes' and 'industrial purposes' of electric arc lighting: Whereas the lacking 'beauty' of electric arc lighting - it was said to be more 'sad' than gas lighting - was an important disadvantage for its use for luxury purposes, for industrial purposes this beauty was only of secondary importance. For enlightening construction sites, harbour work etc. to facilitate nightly labour electric arc lighting was superior: The worker could work better and would not ruin his eyes, while the manager could survey the site. If electric illumination also proved cheaper than gas lighting, its aestethic qualities would become completely irrelevant. Finally, Olsen reminded that arc lighting could also be used indoors, provided that the arc lamp was shielded and provided only indirect lighting via the ceiling.

About the same time, a more detailed analysis of the status of electric lighting was provided by military engineer V. E. Tychsen in an address to the Technical Society. Besides an extensive survey of the available electric lighting equipment, Tychsen paved the way for later discussions on the feasibility of electric lighting by summing up the pros and cons of the new form of illumination relative to gas lighting available in most larger towns. Firstly, there were a number of qualitative criteria. For instance, as electric arc lighting was the lighting source that mostly approached sun light in intensity and colour, it was superior to illuminate labour that involved precision work or view of colours. Also it did not exhaust combustion gasses nor developed heat. In small and badly ventilated rooms, this made gas lighting a health hazard and ruined ceilings and walls. And as electric lighting systems eliminated factors like uncareful handling of gas handles or leaks from gas pipes, they would greatly reduce the danger of fire. Finally, as flexible wires replaced gas pipes, the system could much easier be adjusted to specific lighting demands. Still, Tychsen recognized that for the time being gas lighting still had the advantage of convenience, as each gas light could be switched on and off individually, while electric arc lights were connected in series, so that the switching off of one lamp interrupted the circuit and also put out the other lamps.

And secondly, Tychsen addressed the important issue of the costs of lighting. He could observe much disagreement on this issue abroad. Often this disagreement followed personal sympathies and antipathies, for there were huge financial interests at stake: Electrotechnical equipment manufacturers tried to push electric lighting, while the established gas companies saw electric light as a threat to their business. For instance, according to Paul Jablochkoff - the inventor of the successful Jablochkoff arc light - electric arc lighting was at least four times cheaper than gas lighting of equal intensity. His calculation included investment as well as running costs, the former including the purchase of an engine to drive the dynamo and shields to protect human eyes from direct lighting. If an engine was already available, as it often was in larger factories, and arc light was not shielded (resulting in a decreasing efficiency), electric arc lighting might be cheaper by a factor ten. But a report written for the British gas companies found opposite results: In England, where gas prices were lower than in France, electric lighting would be thirty-five percent more expensive. While there thus remained uncertainty on the cost issue, by the late 1870s Tychsen was not in doubt that the qualitative advantages of electric arc lighting, demonstrated abroad in light houses, harbours, public squares, entertainment establishments, larger factories and public works, also would make it attractive in Denmark.[6]

The introduction of autoproduction systems in Denmark

Although the historical knowledge of early autoproduction installations is rather coincidental and therefore probably rather incomplete, it seems that by 1880 such systems were still a rarity in Denmark. Still, electricity had incidentally been used for experiments and what one may call 'luxury lighting'.[7] For instance, as early as 1857 General Høegh-Guldbergh had bought an electric arc lamp installation, and invited the public to an evening demonstration at the riding ground of the Christiansborg Palace in the heart of Copenhagen. According to a newspaper report, the demonstration indeed proved the great clearness and intensity of electric lighting, for one could read the 'finest writing' from a considerable distance. Yet another experiment to illuminate a fountain with different colours of light 'more suggested than showed the possibility of a great view.'[8] Another known use of early electric lighting is the illumination of a skating party at one of Copenhagen's small lakes in 1871. Few years later, probably inspired by the increasing use of electricity for military purposes stimulated by the Prussian-French war, the technical office of the Danish navy [*Søminevæsenet*] imported the first known mechanical generator in Denmark - a Gramme dynamo - for trials with arc lighting, and would be the centre of Danish electrotechnical knowledge during the 1870s. And, as mentioned above, in the late 1870s the Copenhagen Tivoli had tested how its customers reacted to electric arc lighting. The Tivoli system consisted of a small (six horsepowers) steam locomobile, two generators and two electric arc lamps. The one was placed on a high mast and illuminated the entire Tivoli area in a satisfactory way. The other was shielded and placed at lower altitude near the concert hall. It was this latter lamp, that proved to intense for the public.[9] Notably, few years later - in 1882 - the Tivoli also played a pioneering role in the introduction of electric drive, as it established a small electric railway similar to those the Siemens company had developed for mining purposes, and which had become great public attractions at international exhibitions (figure 2.1). This system included a small (twelve horsepowers) gas engine to drive a Siemens dynamo in a power house. The electricity was then conducted via the rails and wheels to an electromotor driving the locomotive, and returned via an isolated middle rail to the power house.

By the late 1870s, electric lighting was also incidentally used for 'practical purposes'. In February 1878 an electric lighting system had been used to provide nightly illumination to the urgent construction of a stone quay and replacement of the heavy trafficked bridges over the canal surrounding the Christiansborg Palace. This autoproduction system consisted of a steam locomobile driving a Gramme dynamo, which supplied electricity to an electric arc lamp earlier used in the Tivoli (figure 2.2).

With the exception of the system of the Danish Navy, these early autoproduction systems thus had a temporary character. This also included some demonstration projects in the early 1880s, such as a display of the first Danish produced type of generator by professors C. P. Jürgensen and P. L. V. Lorentz (which had obtained a gold medal at the 1881 Paris exhibition) in the private villa of a local gas fitter. This demonstration system, which was open to the public and advertised for Jürgensen's firm [*C. P. Jürgensens mekaniske Etablissement*], consisted a steam engine driving two generators, an arc lamp and thirty-eight incandescent lamps (of the Swan and Maxim types) respectively.[10]

From the late 1870s, also the first civil, permanent autoproduction systems were established. These systems included a lighting system at the large Copenhagen firm Burmeister & Wain, exploiting a ship yard and a machine factory, in 1879. In this case, a Gramme alternating current generator was used to supply eight Jablochkoff arc lights. After four years of operation, the firm was satisfied with this lighting system, which also had given 'considerable economic savings compared to gas lighting.'[11] A number of other permanent systems followed, and by 1886 military engineer N. C. Hansen could observe that although electric lighting was still at its infant stage, it had definitively left the realm of scientific experiment, and had successfully taken up competition with other sources of lighting. He registered seven Danish electrotechnical installation firms, which had installed some forty-four autoproduction systems for different customers. Together these systems supplied forty-seven electric arc lamps and nearly five hundred electric incandescent lamps. Notably, the largest firm in terms of installations was that of C. P. Jürgensen mentioned above, which had installed nineteen autoproduction systems. Another large firm was the Danish Electric Light Company [*Det danske elektriske Lys-kompagni*], which had built twelve systems. If one adds to these systems those installed by foreign firms, such as the early system at Burmeister & Wain's by the French firm Société Générale d'Electricité, or two systems at the naval dockyards by the Anglo-American Light Company and the German company Siemens & Halske respectively, there may well have been over fifty autoproduction systems in Denmark by the mid 1880s.[12]

As Hansen's 1886 survey also shows, these early autoproduction systems were used by a broad range of actors. About half of these systems were placed in industry or workshops, among which distilleries, breweries, sugar factories and the workshops of electrotechnical firms themselves were particularly well represented. The other half included technical schools, the entertainment business, sea going vessels, banks and a number of state institutions such as Parliament, a customs office, and the military.[13]

The diffusion process and the actor groups of autoproduction systems

From then on the diffusion process further accelerated: By the end of 1909, the newly established Electricity Commission had already registered some eight hundred autoproduction systems in Denmark, by 1931 no less than sixteen hundred.[14] Who, then, were the actors primarily responsible for this development? According to the

Electricity Commission, by the end of 1909 about eighty percent of the autoproduction systems were situated in industry. A further classification of those systems, for which the generating capacity was known, is given in table 2.1. As there are several sources of error, the table only provides order of magnitudes.[15]

Of some seven hundred autoproduction systems in the table, including a large number of uncategorized systems, particular large actor groups in terms of number of autoproduction systems were that of butter factories (12% of the total number of autoproduction systems), farms and residence (9%), wood mills (7%), textile mills (6%), flour mills (5%) and machine factories (5%). And although published surveys of autoproduction systems generally excluded the large majority of smaller systems (because they only represented a marginal share of the electricity production), it is certain that the butter and flour branches remained important actor groups for the diffusion of autoproduction systems: As a probably rather incomplete sample (including systems larger than ten kilowatts only) of autoproduction systems of the mid 1920s shows, by then at least two hundred and sixteen butter factories and one hundred twenty-five flour mills autoproduced their electricity.[16] Finally, incidental censuses of agricultural machinery, which included autoproduction systems, suggest that farms became by far the main actor group in the diffusion of autoproduction systems with some two thousand systems by the mid 1940s.[17]

With regard to the importance of autoproduction systems in terms of capacity, and thereby electricity output, there was significant difference between the different actor groups. The autoproduction systems exploited by the large group of butter factories, for instance, had an average capacity of less than three kilowatts in 1910. Indeed, only five out of the eighty-three butter factories that autoproduced electricity had a generating capacity larger than five kilowatts. As we shall see, this was due to the fact that butter factories primarily used autoproduction systems to provide electric lighting, not power. By contrast, other actor groups might exploit autoproduction systems in relatively few but large factories, using electricity to distribute huge amounts of power and therefore have very large autoproduction systems. The primary example is that of the cement industry. By 1910, all seven Danish cement works had autoproduction systems for electricity supply; of these, only one factory had a relatively small system of fourteen kilowatts (corresponding to the largest butter factory system), while the other factories had medium-sized or very large systems with capacities up to more than one megawatt. The average capacity of autoproduction systems in the cement industry was nearly four hundred kilowatts, which was larger than the capacity of many public supply systems in provincial towns.

Table 2.1: Electricity supply systems in Denmark by the end of 1909 according to the registers of the Electricity Commission. Source: National Archives, Elektricitetsrådet (nr 1404), Registre over anmeldelser, B 149.

	Number	Capacity (kW)	Average Capacity (kW)	Capacity range (kW)
Butter factories:	83	204	2.5	1 - 14
Farms & residence:	64	372	6	1 - 23
Wood mills, carpenters etc.:	49	329	7	1 - 32
Textile & clothing factories:	40	1832	46	3 - 240
Flour mills & factories:	39	717	18	1 - 220
Machine shops & factories:	35	2169	62	1 - 1380
Bacon factories:	28	715	26	1 - 90
Breweries:	24	1575	66	1 - 440
Military fortifications:	19	323	17	6 - 75
Railway stations & work-shops:	14	1149	82	21 - 420
Iron foundries:	12	331	28	5 - 88
Cinemas & theatres:	10	146	15	2 - 70
Bread factories:	9	145	16	1 - 77
Paper factories:	9	1836	204	6 - 466
Distilleries:	8	111	14	2 - 54
Prisons, labour camps etc.:	8	467	58	6 - 150
Cement works:	7	2789	398	14 - 1130
Brick works:	7	356	51	4 - 250
Ship yards:	6	1710	285	8 - 625
Electrotechnical industries:	6	1130	188	15 - 528
Margarine factories:	5	351	70	5 - 140
Sugar factories:	5	226	45	22 - 84
Other and uncategorized:	241	6.971	29	-
Public electricity supply:	212	27.970	135	5 - 6.468
Total:	940	53.924	57	-

In terms of capacity, then, very large actor groups exploiting autoproduction systems were the seven cement works (11% of the total autoproduction capacity), some thirty-five machine shops (8%), nine paper factories (7%), six ship yards (7%), some forty textile mills (7%), some twenty-four breweries (6%), fourteen railway stations & work shops (5%) and six electrotechnical manufacturers (4%). Notably, the total capacity of machine factories is distorted as it was completely dominated by on single factory: The machine factory of Burmeister & Wain had a capacity of 1380 kilowatts, and thereby was the largest autoproduction system in the country. Twenty years later, a survey of more than two hundred autoproduction systems larger than thirty kilowatts shows the metal industry, the cement industry, oil mills, sugar factories, breweries (including distilleries) and paper factories as very large actor groups in terms of capacity.[18]

In sum, industry (including butter factories, although these are normally counted - and counted themselves - under agriculture) and to a lesser degree farms were primarily responsible for the impressive diffusion of autoproduction systems up to the 1910s. As the actor group of farms first came to maintain the majority of autoproduction systems much later, and besides early farm autoproduction systems were a kind of spin-off from wind-electric local electricity supply systems developed for village electrification (see the next chapter), the concerns of this actor group will be described in chapter six on the consolidation of autoproduction systems. Within industry, by 1910 there was no single branch that dominated the diffusion of autoproduction systems: The primary candidates, butter factories and cement factories, by 1910 only accounted for just over ten percent in terms of numbers and capacity respectively. Thus there were many actor groups responsible for the diffusion of industrial autoproduction systems. These might also operate their factories under very different circumstances, often defined by the particular character of the production process, and therefore have quite different motives for adopting autoproduction systems. But before studying such motives for selected branches of industry, however, it is also important to notice that there indeed was a common discourse on the feasibility of industrial autoproduction systems in general.

A 'general' discourse on autoproduction systems

The advantages of electric lighting

After the early introduction of autoproduction systems in Denmark, spokesmen of industrial and technical associations continued to make general assessments of the feasibility of autoproduction systems. With regard to electric lighting, they continued to emphasise the qualitative advantages, which had been in focus in the 1870s:

Superior intensity, lack of combustion products and reduced danger of fire. Moreover, since then the innovations of incandescent electric lighting and parallel connection of the lamps around 1880 had removed some of the qualitative disadvantages of early electric arc lighting: Electric incandescent lamps were praised as comfortable to look at and, thanks to its low intensity compared to arc lamps, suitable for indoor lighting. And parallel connection enabled the switching on and off of each lamp individually, just like in the gas lighting system.

In an address to the Technical Society on electric lighting in the mid 1880s, military engineer C. Juul examined the qualitative advantages of electric lighting in greater detail. While he found traditional urban gas lighting still suitable for street lighting because of its cheapness and reliability, he stressed the disadvantages of gas lighting indoors. With regard to the danger of fire, open gas cocks or leaking gas pipes indeed had caused many fires, and the safety of gas lighting depended not in the least upon the careful handling of the system by its users. In case of electric lighting, by contrast, users were not a danger factor, and fires could be almost completely avoided by a careful construction of the system, including the use of fuses. He also investigated the 'main disadvantages of gas lighting' of producing an uncomfortable and oppressive atmosphere more closely: According to a measurement of the production of combustion gases from different forms of lighting, the traditional lighting sources (gas, paraffin, oil and wax lamps) produced significant amounts of carbon dioxide and water. In addition, Juul expected that there could be more poisonous combustion products 'which could not yet be chemically identified.' Although the amount of combustion gases varied with the types of burner used (a new regenerative burner even transported combustion gases out of the room, but was left out of consideration), electric light had the clear advantage of zero pollution. Moreover, measurement of the heat production of the available lighting sources showed that the heat production of electric arc and incandescent lamps was marginal relative to all other lighting sources. In gas lighting, for instance, ninety percent of the energy was transformed into heat. Finally, also Juul briefly mentioned how fine sod particles stemming from combustion ruined carpets and expensive paintings, and how its heat and flickering tired the eyes. Electric incandescent lighting had none of the disadvantages mentioned, and should - according to Juul - be introduced 'everywhere, where the cost of lighting were of secondary importance.' This included in particular public buildings.

While these qualitative advantages of electric lighting were generally accepted part of the rhetoric in favour of electric lighting, the costs of electric lighting relative to traditional lighting sources was subject to more uncertainty and change. In the mid 1880s, Juul had acknowledged that the available investigations lacked reliable data stemming from experience. Yet he did make some general statements for electricity autoproduction systems competing with purchase of gas from a local gas company. As the autoproduction system included the purchase of production equipment as well as distribution and consumption equipment, its investment costs were of course relatively large. On the other hand, its running costs might be significantly lower than those of gas lighting, not in the least because the gas companies took a profit for gas supply, while autoproduced electricity would be available at cost price. In sum, Juul expected that electric incandescent lighting would be at least as expensive as gas lighting and as a rule more expensive, while electric arc lighting undoubtedly was cheaper - but had a more limited range of application.[19]

A few years later, in a more detailed treatise on the subject, also engineer Conrad Zarthmann found that purchased gas lighting would be cheaper than electric lighting from an autoproduction system, at least if the latter had a low running time of some two-three hours daily throughout the year.[20] For in such cases the relatively high investment costs meant, that the high fixed costs of interest and repayment dominated the running costs in the annual cost picture, and gave autoproduction systems the disadvantage. Yet he acknowledged that one could not to make a general economic assessment for autoproduction systems as easy as for public electricity supply systems, as the conditions for operation might differ from system to system. For instance, if the electricity generator could be powered by an already existing, large and steady going steam engine, the investment costs excluded a power engine and thus were greatly reduced. This was for instance the case in textile mills. Furthermore, an increase in running time of the autoproduction system would decrease the relative weight of the annual fixed costs relative to the running costs (in other words, the investment would be returned sooner), and thereby improve its economic feasibility. As a result, the economic feasibility of autoproduction in firms using electric lighting some two-three hours daily differed greatly from its feasibility in firms, which operated during nighttime also, or which required artificial lighting during daytime, for instance because part of the production happened underground.[21] In these latter cases, autoproduction systems for electric lighting surely could be feasible.

Still, these criteria of the availability of motive power and running time could be included in general guidelines on the economic feasibility of autoproduction systems for electric lighting. An example is the very detailed study of factory lighting in the Stuttgart area in Germany, published in the journal of the German engineering society *Verein deutscher Ingenieure* and extensively referred in a Danish industrial journal in 1890. The investigation showed that economic feasibility of autoproduced electric incandescent lighting relative to purchased gas lighting improved with the size of the system, the availability of a prime mover and the running time: An electricity autoproduction system supplying one hundred and fifty electric incandescent lamps, for instance, would be economically feasible either if a steam engine was available, but also if the running time exceeded twelve hundred hours annually. A system of three hundred electric incandescent lamps, likewise, would be feasible either if a steam engine was available, or if the running time exceeded eight hundred hours annually.[22]

The pros and cons of electric power transmission

With regard to electric drive, the issue of economic feasibility had been addressed occasionally in the 1880s for the case of electric power purchase from an electric utility. For such power purchase had several clear advantages for small industries. Power purchase avoided not only the expenses, but also the space and maintenance demands of running their own engines. In addition, contrary to other power sources, there existed electric motors for very small capacities for use in for instance sewing machines, ventilators, printing presses and handicraft tools. The German manufacturer Siemens & Halske produced electric motors with capacities down to a 150 watts.[23]

When electric drive became more popular in the early decades of the twentieth century, agitation for this form of power supply mainly came from advocates of electrotechnology, which had begun to organise and publish their own journals, such as the *Elektroteknisk Tidsskrift* from 1897 and *Elektroteknikeren* from 1904 - the latter being the organ of the newly established Electrotechnical Society [*Elektroteknisk Forening*]. By the 1910s, several arguments had stabilized into a fairly standard rhetoric repertoire. In this repertoire, there might also be a distinction in qualitative and economical advantages like for electric lighting. But with regard to electric power these were also mutually dependent variables, since qualitative changes in power supply usually gave significant economic savings as well.

The main qualitative advantage of electric drive was its possibility for group or individual drive of the machines in a factory. In traditional power supply systems in most factories, power was produced centrally by a single prime mover, often a steam engine, and then transported through the factory through a mechanical transmission systems consisting of iron or steel 'line shafts'. Vertical shafts through holes in the ceiling might provide power to the different flours of the factory, where horizontal shafts again delivered the power to the individual machines. Leather belts on pulleys were used to connect the shafts with the engine, machines or each other. Departing from such a system of 'direct drive', electric drive could be introduced at several levels. The central prime mover could be replaced by a large electromotor, so that the mechanical transmission system was maintained. Such a system of 'electric line shaft drive' might be attractive if electricity could be purchased cheaply; the advantages of autoproducing electricity were minimal, however, as it would mere involve the extra conversion of turning steam power into electric power. The systems of 'electric group drive' and 'electric single drive', by contrast, replaced mechanical power transmission with electric power transmission within the factory and thereby had several advantages, which made also autoproduction of electricity attractive. In case of electric group drive, electricity was produced centrally (or bought), and then transported through electric wires to several decentral electromotors, which each drove a local line shaft running a group of machines with similar power requirements. And in case of electric single drive or 'individual drive', each machine in the factory was powered by its own electromotor, and power transmission between the central power house and machine made completely electrical. Finally, in a system of 'unit drive', single large machines might be divided into different sections with different power requirements, each powered by their own electromotor. In these case, even mechanical transmissions within machines were replaced by electrical ones.[24]

According to advocates of electric drive, the degree of decentralisation of motor drive might have several economic gains.[25] For instance, electric power transmission could reduce the power losses and thereby the fuel consumption of the factory. For larger mechanical transmission systems might have huge power losses due to friction, the slipping of belts etc. It was acknowledged that electric group or single drive also included losses: The process of centrally converting mechanical energy into electrical energy, transporting it and then decentrally converting it back to mechanical energy involved considerable conversion losses, but relatively small transport losses. In larger factories, therefore, electric power transmission would reduce the total power losses.

Secondly, as electric wires could easily be lead across the factory, electric power transmission implied more flexibility in the design of the factory. This in turn facilitated a rationalization of the production process: Whereas the machines previously had been situated according to their power requirements in the mechanical power transmission systems, they could now be placed according to their function in the production process. Besides a rationalisation of the production process, this also enabled the use of cheaper factory buildings.

And thirdly, the decentralization of motor drive had the important advantage that idle machines or machine groups could be switched off and thus not consume any power. In case of line shaft drive, idle machines were either kept running, or the transmission belt running the machine was shifted over to an idler pulley. Still, even in the latter case the entire transmission system of shafts and belts was still running and consumed power from the central engine. Also in this way single or group drive decreased the power consumption of the factory, and thereby the fuel costs.

Finally, electric drive also facilitated increased control with the power consumption in the factory as well as social control and motivation of the workers.[26] In a mechanical transmission system, the only indicator of operation was the power production measured in terms of fuel. Yet in electric transmission systems, ampère-meters indicated the power consumption at any given moment, while wattmeters indicated energy consumption over longer periods of time. This increased control would hardly motivate the introduction of electric drive by itself, but be an important advantage as 'the power consumption of any moment could directly be translated into money.'[27] And with regard to social control and motivation of the workers, it was argued that volt and ampère meters could be placed in the director's office, who would then be able to follow the operation of the factory. Moreover, the machine engineer could read his performance on such meters, and would be motivated to adapt power production to the actual power demand and thus optimize fuel economy of the factory

On the other hand, there were also some economical drawbacks of decentral motor drive facilitated by electric power transmission. For instance, in a system of individual drive each electromotor should be large enough to supply the maximum demand of the single machine. As the maximal power demands of machines normally did not coincide, however, a central power engine in a system of line shaft drive was normally designed for a smaller capacity than the sum of the maxima of machine capacities. Decentralisation of motor drive therefore entailed an increase in the installed capacity and thus in investment costs. In addition, due to simple economies of scale the investment in a large number of small motors was more expensive than the investment in one large engine per unit of capacity. In sum, the economic savings of electric power transmission might be cancelled by the higher investments costs in electric motors.

Although such general advantages and disadvantages were easily summed up, representatives of electrotechnology knew that it was impossible to make a reliable assessment of the feasibility of autoproduction of electric power in industry in general. Depending heavily upon the context of application, this feasibility varied from industry to industry and with local conditions.[28] In these cases, they might enter a discussion with specific actor groups on the advantages of electric drive in their particular industry. The following sections address the specific situations of different industries.

Electricity in context I: Electric lighting in the butter industry

General background

To understand how the butter industry became a 'leading sector' in the diffusion of autoproduction systems by using many but small systems, several general

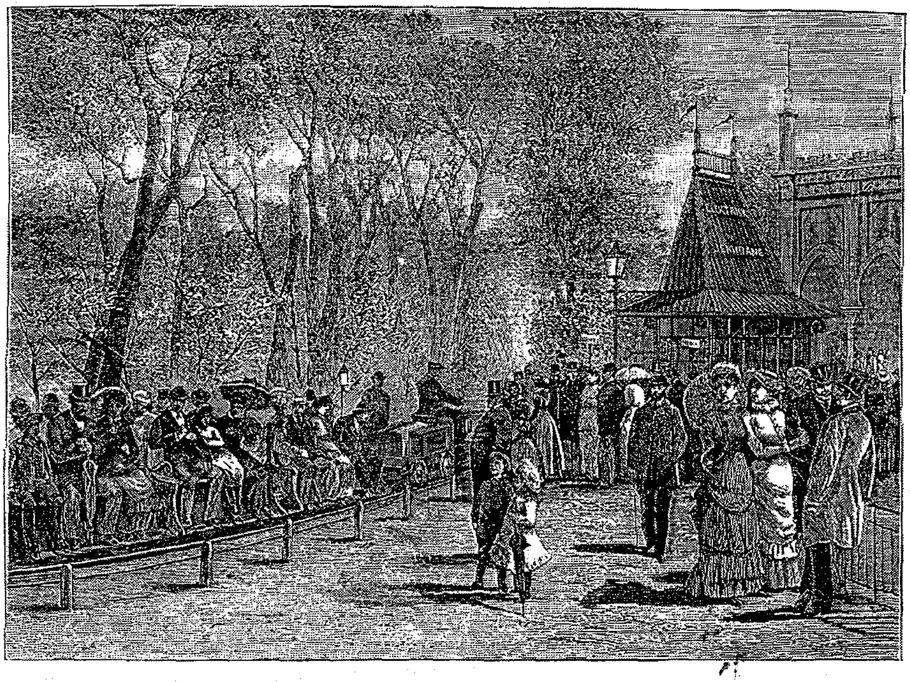


Figure 2.1: Electric railway at the Copenhagen Tivoli in 1882. Source: Illustreret Tidende Vol. 23 (1881-82), nr. 1181: 405.

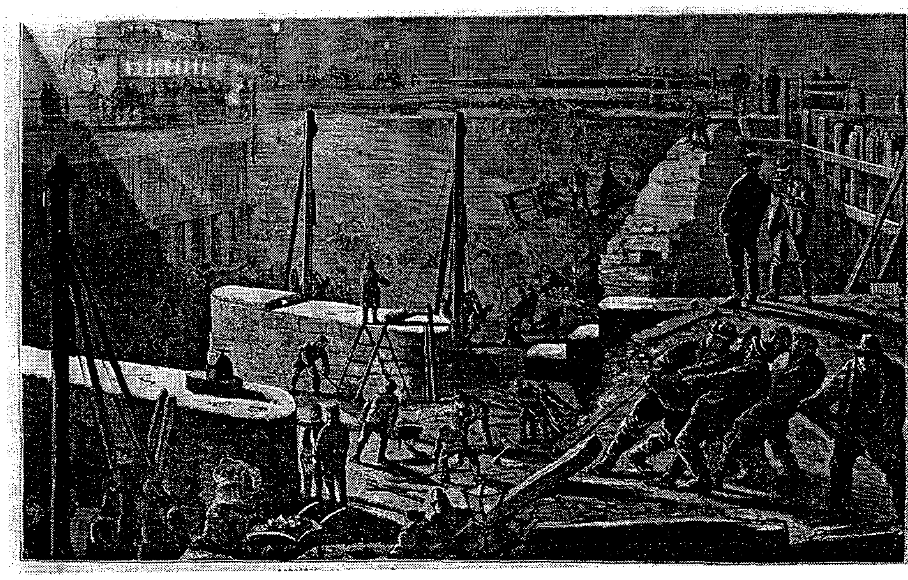


Figure 2.2: Electric arc illumination of nightly labour at the 'Holmens bro' bridge in Copenhagen in 1878. Source: Illusteret Tidende Vol. 20 (1878-79), nr. 1003: 116.

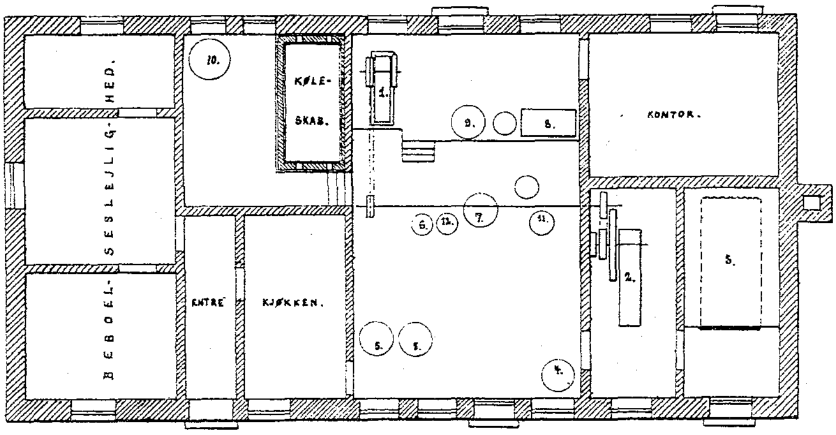


Figure 2.3: The Havrebjerg dairy near Slagelse on Zealand represents a typical Danish co-operative butter factory in the mid 1890s, apart from the fact that it was among the first to perform experiments with a refrigerator. The physical context was a comparatively small building (18 x 9 metres), including an apartment for the manager (to the left). Legend: 1= Cooling machine; 2= Steam engine; 3= Boiler; 4= warm water tank; 5= Churns; 6= Cooler; 7 and 11= Centrifugal separators; 8= Cow milk tank; 9= Skim-milk tank; 10= Butter kneading machine; 12= Cream pasteurizer. Source: Philipsen 1895.

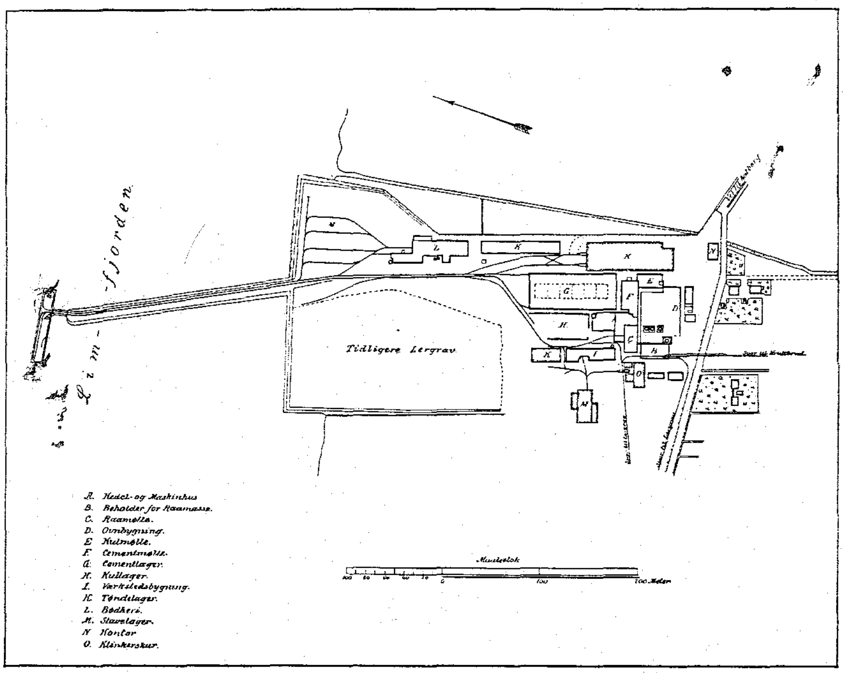


Figure 2.4: The cement factory 'Norden' at the Limfjorden in the early 1920s demonstrates the geographical expansion of cement factories. With a diameter of some three-four hundred metres excluding the chalk and clay quarries, the cement production site was much larger than the butter production site. Legend: A= Engine house; B= Slurry basin; C= Slurry grinder; D= Kiln building; E= Coal grinder; F= Cement grinder; G= Cement silo; H= Coal silo; I= Machine shop; K= Barrel storage; L= Cooper's shop; M=Stave storage; N= Office; O= Clinker silo. The scheme also includes the old clay quarry ['tidligere lergrav') and tracs to the current clay ['spor til lergrav'] and chalk ['spor til kridtbrud] quarries. Source: Drachmann 1923, 45.

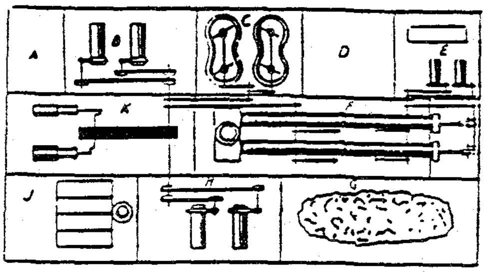


Figure a: Mechanical drive. A= Initial crushing; B= Slurry grinders; C= Stirring mechanisms for the slurry; D= Hardcoal storage; E= Hardcoal grinders; F= Rotary kilns; G= Clinker hall; H= Cement grinders; J= Steam boiler; K= Central steam engine.

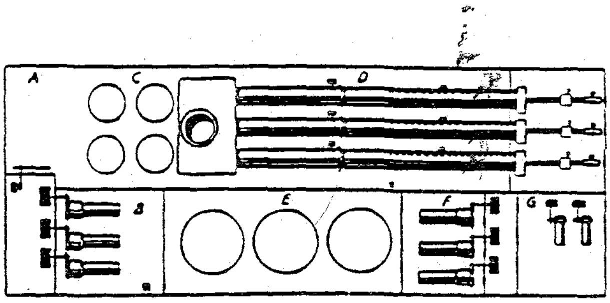


Figure b: Individual electric drive (excl. power station). A= Initial crushing; B= Slurry grinders; C= Slurry storage; D= Rotary kilns; E= Clinker silos; F= Cement grinders; G= Hardcoal grinders; ■= Electromotor.

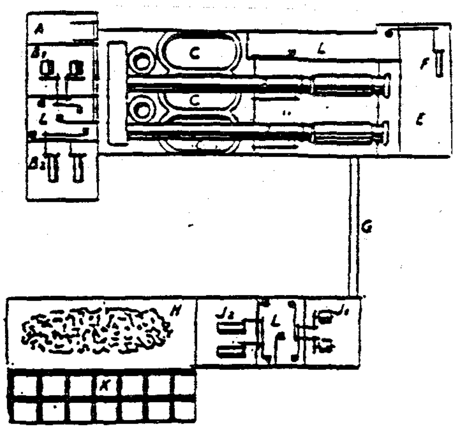


Figure c: Group electric drive (excl. power station). A= Initial crushing; B= Slurry grinders; C= Slurry basin; D= Rotary kilns; E= Hardcoal storage; F= Hardcoal grinders clinker silos; F= Cement grinders; G= Clinker transport; H= Clinker hall; J= Cement grinders; K= Cement silos; L= Motor rooms; ■= Electromotor.

Figures 2.5 a, b and c: Basic scheme of a cement factory (wet process) with mechanical drive, with individual electric drive and with group electric drive. Source: "Elektriciteten i Cementfabrikkerne", Elektroteknisk Tidsskrift (1913/14), Vol. 18: pp. 93-94.

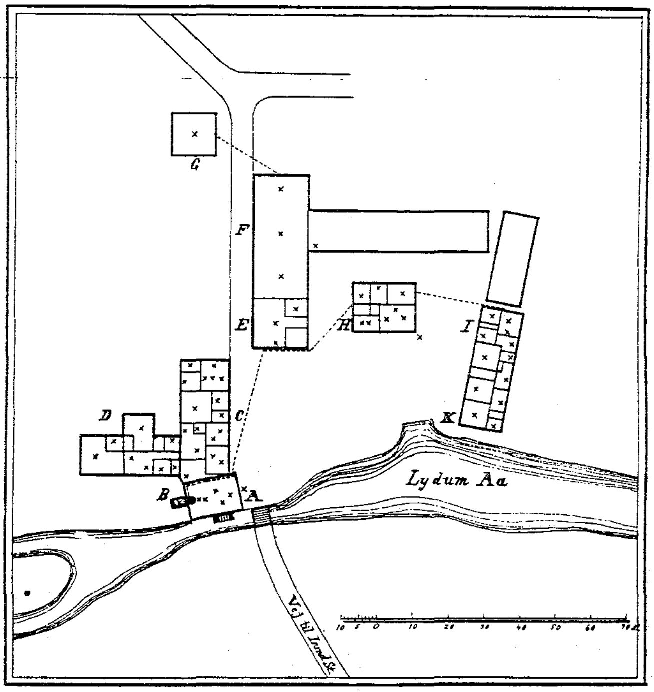


Figure 2.6: The electric lighting system of the Lydum watermill in 1904. The dynamo and the accumulator were situated in the mill (A), and supplied lamps (marked with an 'x') in the court yard as well as the miller's house (B & C), horsestable (E), cow stable (F), pig stable (G), shop with storage facilities (H) and two appartments (I & K). Source: Tidsskrift for vindelektrisitet 1904/5, 24.

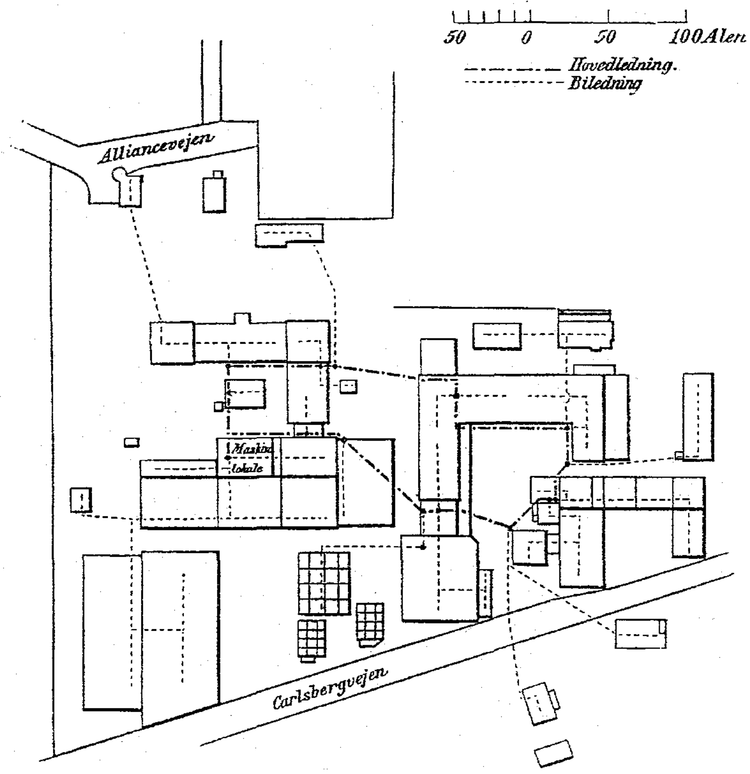


Figure 2.7: The distribution network of the electric lighting system at the premises of the Old Carlsberg brewery in Copenhagen in the early 1890s, including an engine room ['Maskinlokale'], a main distribution ring ['Hovedledning'] and secondary wires ['Biledning']. Source: Hauberg 1891-92, 34.

background factors are relevant, including the organisational structure of the dairy branch and the technical structure of the individual production sites. Notably, the number of butter factories in Denmark was very large. When the issue of using electricity in the dairy branch was taken up around the turn of the century, Danish butter production had recently been transferred from the single manor and farm dairies to some twelve hundred small butter factories (possibly including some cheese production), which concentrated butter production only at the level of the village or the parish.[29] Although this development had been started in the 1860s by butter merchants, who sought to produce large and homogeneous quantities of farm butter and thereby make farm butter available for the flourishing export to Great Britain, this development was decisively stimulated by two innovations of the late 1870s and early 1880s: On one hand, the technical innovation of the continuous centrifugal separator enabled the separation of cream from milk in a continuous process well suited for larger production sites. And on the other hand, the social innovation of co-operative ownership of the butter factory enabled the farmers to own and run these butter factories themselves. Although the notion of co-operation was known from abroad, its use in the production sector rather than in the trade and distribution sectors has been characterized as a Danish invention without foreign precedents.[30] It coincided with a social movement of emancipation of rural Denmark, and allowed farmers to eliminate the town merchant as a mediator in the dairy business. Danish butter factories, therefore, were mostly co-operatively owned by the milk suppliers (that is, the farmers) with the declared aim to increase the profits of the latter. They jointly raised the capital under joint liability, and appointed an executive board to supervise the dairy, which again employed a dairy manager and personnel for daily operation. And with regard to the material flow, farmers not only supplied cow milk to their dairy, but also received its 'waste products' like skim-milk and churn milk for consumption at the farm.

This formula proved extremely successful. Danish farmers massively engaged in the founding of new butter factories, and a few decades later virtually every village or parish had its co-operative dairy. By the turn of the century, about eighty percent of Danish butter production occurred in more than twelve hundred small butter factories, of which more than a thousand were co-operatively owned.[31] Simultaneously, Danish export butter gained a dominating position on the British market, while Danish butter factories became a leading sector in Denmark with regard to exports, economic prosperity and technological innovation.[32]

It is also important to notice the high degree of organisation of the Danish dairy branch, which again affected the choice of technology. From its early revival in the 1860s, the dairy branch had been embedded in a web of local, regional and national interest organizations, research facilities - from the early 1880s in a separate agricultural test laboratory situated at the Royal school of agriculture [*Den Kongelige Vetrinær og Landbohøjskole*, KVL], and an information infrastructure for spreading research results and general experiences in the form of travelling courses and journals. This network was a precondition for the rapid diffusion of butter factories throughout the country, and was strengthened by it, as the co-operative movement arose from the 1890s. Despite the very large number of butter factories, then, the single dairy had a high inclusion in the common discourse and behaviour, and the branch as such acted in a rather homogeneous way.

Correspondingly, Danish butter factories were also remarkably similar in their technical layout.[33] Butter production was an indoor activity in a comparatively small building relative to the factories of many other branches of industry (figure 2.3). The production process consisted of three steps: The raw material of cow milk was separated in cream and skim-milk. The cream was then churned to butter, and finally salted and kneaded. These three steps were mechanized by machinal separators, churns and kneading machines. Power was in almost all cases provided by a small steam engine with an average capacity of merely four kilowatts. Indeed, the production machinery had a rather modest power demand; by the late 1880s the machine factory of Koefoed & Hauberg produced centrifugal separators with a capacity of one kilowatt or less, and claimed that a four kilowatt steam engine was sufficient for the processing of six thousand pounds of milk per hour: Half of the capacity was used to drive three centrifugal separators, the other half to drive two churns, three pumps, one kneading machine, and one oil cake crusher.[34]

Finally, the production process included the pasteurization of the separation products, skim-milk and cream, which would affect the process of electrification via to the large heating demand of the butter factory. With the centralization of milk processing from the single farm to the co-operative village factory, which returned the skim-milk to its suppliers, butter factories rapidly became centres for epidemics of particularly typhus, diphtheria, and possibly (it was not yet known) the emerging tuberculosis. Following Louis Pasteur's observation that the dangerous microorganisms could be killed by heating to more than eighty degrees Celsius ('high-pasteurizing'), nearly all Danish dairies had introduced pasteurization of the skim-milk in the years 1886-88 and pasteurization of the cream in the first half of the 1890s. While rural representatives in Parliament had been able to stop a law restricting dairy operation in the 1880s, in the late 1890s a 'pasteurization act' even made the pasteurization of skim-milk for consumption - now mostly by animals at the farm - as well as cream for export butter obligatory.[35] In addition to such pasteurization, from the mid 1890s also cooling machines were rapidly introduced to cool the products after separation, thereby preventing new bacterial attacks.

The pros and cons of electric lighting

When electricity was placed on the agenda of dairy organisations and journals in the late 1890s, it was with sole reference to electric lighting. To be sure, the issue of electric drive had been incidentally raised from the early 1890s, when it was observed that foreign dairies used electric power transmission to gain access to nearby hydropower. Moreover, in the mid 1890s the leading dairy journal *Mælkeritidende* introduced the technology of electric drive as well as lighting to its readers. And in the late 1890s, the newly started electrotechnical journal *Elektroteknisk Tidsskrift* presented arguments to introduce electric drive in Danish butter factories, arguing that single drive was the optimal solution to the changing power demand of centrifugal separators.[36] Yet, within the dairy branch it was broadly agreed upon that the steam engines and the small mechanical transmission systems functioned satisfactorily. Steam engines were not only a reliable power source but also a cheap one, due to the large heat demand of modern butter factories: The steam boiler had to produce large amounts of steam for pasteurization, and if this steam was led through a steam engine, motive power could be produced with a small fraction of its energy content (less than five percent), whereafter it could be used for heating. As a result, already at the turn of the century power was seen as a 'by-product' of heat production, which was obtained with only a very small increase in fuel consumption.[37]

In view of the new possibility of electric lighting, however, the traditional lighting source of butter factories was increasingly problematised. Contrary to towns, where electric lighting competed with gas lighting, in rural Denmark electric lighting competed with paraffin lamps. As the expert in rural electricity supply, Professor Poul la Cour of the Askov folk high school (see the next chapter), put it at the annual meeting of Danish dairy managers in 1899, it was the application in lighting that made electricity interesting for Danish butter factories, as it enabled 'the abolition of the unsuitable paraffin lamps.'[38] Indeed the following discussions on electric lighting in the dairy journal expressed broad agreement that paraffin lamps were a nuisance in dairies. First, paraffine lamps provided 'bad' lighting. Their light was not very intense (partly because the smoke on the glass shades decreased the lighting) and flickered in the damp and drafty dairy buildings. Particularly in old buildings with low ceilings, this provided poor conditions for precision work. Second, as paraffin lamps produced smoke, sod particles would be transported via hands or via the air to pollute the milk, cream and butter. For these reasons, observers problematised paraffin lamps as a poor condition for hygiene in the butter factory, which was regarded 'a main criterion in all aspects of operation.'[39] In addition, other disadvantages of paraffin lamps mentioned in the discussions were the inclination of glass shades to explode due to condensed water falling from the ceiling, as well as the considerable maintenance effort - besides daily lighting and extinguishing, this included cleaning, replacing glass shades and filling up with paraffin. Electric incandescent lamps for indoor lighting in dairies lacked all these disadvantages, and were therefore presented as an important improvement, both by spokesmen of the dairy branch and by representatives of individual butter factories, which had adopted electric lighting and wished to share their experience with colleagues - as was customary in the Danish dairy tradition.[40]

The costs of electric lighting, however, was an issue of more controversy. On one hand, the participants in the discussion agreed that autoproduction systems for electric lighting in principle could be very cheap, since motive power was available from the steam engines. Even though these were generally small as mentioned above, the lighting demand in these small buildings was only a fraction of its capacity. According to one supplier of autoproduction systems, a small butter factory could do with some ten electric incandescent lamps, a larger one with some twenty lamps.[41] Danish butter factories therefore only had to acquire a very small dynamo with a capacity of one or two kilowatts, relatively short wires, relatively few lamps and some volt- and ampèremeters. Such a system could be purchased for the low price of about five hundred DKK.[42] And while the investment costs of autoproduction systems for electric lighting thus were low, the running costs were low too, since as mentioned above motive power was obtained very cheaply due to the use of steam for heating. As state-employed agricultural consultant C. V. Birk concluded, the extra power demand of about one kilowatt for lighting would hardly be noticed economically.[43]

On the other hand, in this scheme electric lighting would be available only when the steam engine was running. For lighting outside the running hours, either the old paraffin lamps had to be maintained, or an accumulator had to be added to the electricity supply system. In either case the economic advantages of electric lighting decreased: If paraffin lamps were to be used next to electric lighting, there would be no savings relative to the traditional form of lighting, while the other option of an accumulator doubled the price of the autoproduction system. In addition, accumulators were difficult and expensive to maintain. Incidental critics, such as a representative from the butter factory of Klejtrup near Hobro in Northern Jutland, feared that electric lighting was too expensive and recommended his colleagues to wait with investment in the new lighting technology.[44]

The choice for electric lighting autoproduction systems

Nevertheless, around the turn of the century several representatives of individual butter factories presented their newly established systems in the journal *Mælkeritidende*, expressed their satisfaction with these systems and recommended their colleagues to invest in electric lighting as soon as possible. An example is dairy manager A. M. Andersen's description of the electric lighting system in the butter factory in Langaa in Northern Jutland in 1899. The system, which had been operational for more than a year, consisted of a small dynamo and an accumulator, a switchboard with a volt and ammeter, and wires connecting eighteen incandescent lamps. Two of these illuminated the power room - the steam engine and the boiler respectively. Four lamps illuminated the milk processing room: These were situated near the cow milk weight, the skim-milk weight, the churns and the separators respectively. Finally, two lamps illuminated the butter and cheese making rooms, while the remaining lamps illuminated the kitchen, office, living room, dining room and bedrooms of the attached apartment. Andersen stressed that he was most satisfied with the installation, with reference to the qualitative advantages of electric lighting relative to paraffin lighting; moreover, he argued that electric lighting also proved cheaper than paraffin lighting, because the motive power was available in the form of a steam engine, and an increase in coal consumption from the small dynamo could not be noticed.[45]

In other cases, representatives of single dairies agreed that accumulators made the system more expensive. Some, like Jens Christensen of the Aastruplund butter factory in Eastern Jutland, accepted the higher costs of a fully equipped electric lighting system in order to obtain the important qualitative advantages of electric lighting. This dairy operated a comparatively large system of forty electric incandescent lamps from 1901, including an accumulator. In this large system the dynamo demanded quite some power, but as the extra steam produced could be fully employed for heating in the production process, the increased coal consumption played a marginal role.[46] Others, by contrast, simply avoided accumulators. For instance, in the late 1890s the co-operative dairy in Karise South of Køge on Zealand opted for a small system without accumulator, supplying merely eight electric incandescent lamps. Outside the running hours, the dairy still used paraffin lamps. Besides qualitative advantages, the price of electric lighting was found comparable to that of paraffin lighting, and as K. C. Knudsen put it in an address to the association of local agricultural societies on Zealand, his experience with this system led him to recommend "an immediate start to illuminate all our dairies with electric lighting."[47] In another case of the dairy Fælleshaab near Rødby on Lolland, which installed electric lighting in 1901, the plant manager simply ordered the engine operator to meet a quarter of an hour earlier at work, so that the machinery was always running during the working hours. Also he was most satisfied with the qualitative advantages as well as the economy of autoproduced electric lighting.[48]

Finally, illustrative for the use of technical science in the Danish dairy branch as well as the importance of the lighting issue around the turn of the century, the agricultural laboratory of the agricultural school was involved to investigate the issue and provide closure of the disagreement. As the chairmen of regional associations of butter factories put it in an address to the laboratory in 1900, an investigation of better and cleaner lighting in dairies was necessary to provide a basis for the decision of the individual dairy manager. Besides the traditional paraffin lighting and electric lighting, also the new acetylene gas lighting was included as an option. The report was published in 1903, several years after the diffusion of electric lighting systems in the dairy branch had started, and included besides test results detailed guidelines for installation of electric and acetylene lighting systems.[49] With regard to the choice of lighting system, the report confirmed that the running expenses of the electric lighting systems were marginal, provided that the steam engine was large enough to draw the dynamo, and that additional steam production could be used in the production process. The only economic factor, then, were the investment costs. If these were not very much higher than those of the alternatives, electric lighting was to be preferred due to its important qualitative advantages - it was simply the best form of artificial lighting. For the same reason the report recommended fully equipped systems including expensive accumulators, for 'a good acetylene gas system was preferable to a badly equipped electric lighting system.' In the concrete tests, the investment costs of good electric lighting systems were less than two thousand DKK, including accumulator and lamps wherever wanted. The annual costs of interest and repayment were set at 240 DKK, which was about the same as the annual costs of acetylene lighting and slightly higher than those of paraffin lighting. Still, it was unambiguously stressed that the qualitative advantages of electric lighting should outweigh the possible economic savings of paraffin lighting.

With this final authoritative recommendation of electric lighting and the specific dairy context of cheap power production, small lighting demand and dissatisfying traditional lighting sources, in the first decade of the century Danish butter factories often opted for electric lighting. While a number of them connected to new local public electricity supply systems, which were rapidly established in second half of the decade (see the next chapter), a large number invested in autoproduction systems and thereby made the dairy branch a leading sector for the diffusion of autoproduction systems. With regard to the technological style of these systems, these were characterized by their small scale: They often included a generator smaller than two kilowatts, supplied a small number of incandescent lamps, and used very low (and thus cheap) distribution voltages to cross brief distances. While one observer found fifty or sixty-five volts appropriate for butter factories, a number of early dairy systems even used thirty volts systems.[50]

Electricity in context II: Electric light & power in the cement industry

General background

The situation of the cement industry in Denmark differed from that of the butter industry in several aspects.[51] While the latter was characterized by very many but quite small factories, the production of cement was concentrated in few but very large factories, both in terms of physical expansion and power demand. The production of hard-burnt so-called Portland cement, applied as an hydraulic mortar (i.e. hardening in air as well as in water) or mixed with small stones as concrete, had been introduced in Denmark from the late 1860s. Yet the first Danish cement factories, situated on Zealand, were comparatively small, and did not last beyond the 1880s. Instead the Danish cement industry emerged around two areas of the Limfjorden fjord and the Mariager fjord in Northern Jutland, residing over huge chalk deposits for raw material and providing access for deep-draught vessels for transport of the large amounts of hardcoal used and the comparatively heavy and voluminous product. By the turn of the century, there were merely five Danish cement factories, and three others were established before the outbreak of the First World War, whereafter the number again decreased.

Also from the beginning of the century, the competition between these factories had been reduced through the establishment of a cartel dominated by the firm Aalborg Portland Cement Factory, Ltd. [*Aalborg Portland Cementfabrik*, in turn partly owned by the cement factory manufacturer *F. L. Smidth & Co*, currently *FLS industries*] which operated the largest Danish cement factory at Rørdal near Aalborg at the Limfjorden. The cartel gradually evolved to include all but one factory in 1920, which in the 1930s formally amalgamated into Aalborg Portland, Ltd. Competition came only from the Danish Co-operative Cement Factory [*Dansk Andels Cement-fabrik*] in Nørresundby at the Limfjorden, established under the co-operative movement in 1913 as a direct response to the cartelisation of the industry, and having a market share of a fifth to a fourth for the period under consideration. As a result of this concentration, technological choices were hardly affected by journals as in the case of the dairy branch, but made within the large firms which had developed expert technical knowledge.

Already by the turn of the century, cement factory premises were very large and included of a number of sections for outdoor as well as indoor activities (figure 2.4).[52] First, the factory premises were situated to include large chalk and clay quarries, where the raw materials were gathered largely by hand. From there, the chalk and clay were transported to the next section of the factory by means of dumping waggons on tracks, normally pulled by horses. In this second section, the raw materials were ground and mixed to prepare them for further treatment. This was increasingly achieved by the so-called wet process, which dominated in Denmark for the entire period under consideration: The clay and chalk were diluted in large basins, and the resulting slurry pumped into tube grinders (hollow, fast revolving cylinders containing flint stones), which ground the slurry. Finally they were mixed in the correct proportions in mixing basins.

Third, the slurry was pumped from the basins to the kiln section, where it entered at the top end of so-called rotary kilns, which were rapidly introduced in Denmark from the late 1890s. These were long, slightly sloping and slowly rotating hollow cylinders, where the raw material entered continuously at the higher end and an incoming jet of air and powdered hardcoal was burned at the lower end. As the slurry descended in the kiln, it first dried, then was gradually heated (and calcined) and finally sintered at the lower end at temperatures of 1400-1500 degrees Celsius. The resulting clinker (small balls of cement with the size of a walnut) then passed through a likewise slowly revolving and sloping cooling-cylinder, where it was cooled by an air jet. Fourth, the clinker was kept in storage silos for several days to improve quality and grindability, before it was ground to powder in the tube grinders of the grinding section. Finally, the cement was packed in a packing section. In addition to these sections constituting the main production line, the factory would contain a large hardcoal grinding section, where the imported hardcoal was stored, dried and ground to powder in tube grinders. From there, it was injected at the lower end of the kiln together with the preheated air jet from the cooling cylinder.

There was thus a very large power demand for the raw material grinders, the stirring mechanisms in the slurry basins, the kiln rotators, the cement grinders and the hardcoal grinders. In addition, there were ventilators, transport machines and pumps. Together, these machines had a large power consumption and placed cement factories among the most power intensive factories in Danish industry, as their average power consumption surpassed that of ship yards, cotton mills and paper factories.[53] Among them, the slurry and cement grinders were the most power intensive machines, consuming no less than two-thirds of the total power requirement of the factory.[54]

Electric lighting in the cement industry

Although it was the introduction of electric drive that made the cement industry extremely electricity-intensive and therefore interesting for this study, electric lighting of course preceded electric drive. As cement factories - contrary to butter factories - were run day and night, already the first cement factories of the 1880s and 90s were very interested in electric lighting systems. The oldest cement factory in Jutland, Cimbria near Hobro at the Mariager Fjord, installed an electric lighting system by the mid 1880s. Electricity was produced on a six kilowatts dynamo, which was powered by the main steam engine of the factory, and supplied some forty incandescent lamps for indoor lighting as well as the outside of the engine house and the kilns. Furthermore, it supplied three bright arc lights at the slurry basin, the harbour and the chalk quarry respectively. Electric lighting was to facilitate the factory to operate during the night; bright electric lighting of the chalk quarry, for instance, enabled the workers to continue in shifts throughout the night and satisfy the large chalk demand of the factory. The lesser nightly demand of clay, by contrast, was stocked during the day. The large size of the system is also illustrated by its distribution voltage of 110 volts, much higher than that of dairies and comparable to that of contemporary public electricity supply systems in large cities as New York and Berlin.[55] Also Aalborg Portland's Rørdal factory (1891) and the factory 'Norden' (1900) at the Limfjorden were from the beginning equipped with electric lighting systems to facilitate nightly labour at the chalk quarries and the factories.[56]

Electric power

With regard to the particular advantages of electric drive in the cement industry, a discussion in cement journals was lacking, but electrotechnical journals indeed provided what may be called an agitation for electric drive in cement factories, in the same way that they agitated for electric drive in other industries. Their information was often taken directly from German electrotechnical firms as Siemens-Schuckert and Allgemeine Elektricitäts-Gesellschafft (AEG), which had electrified several large cement factories in Germany and recognized the cement industry as a large potential customer of equipment.[57] For instance, inspired by a publication of the AEG company on the issue, the *Elektroteknisk Tidsskrift* repeatedly recommended electric drive in the cement industry for all machinery.[58] Several of the above mentioned arguments for electric drive applied in particular to this industry: Thus, the particular large mechanical transmission systems in these spacious factories caused very large power losses, and in large factories (larger than 300.000 barrels of cement produced annually) these would always exceed the losses of electric power transmission. In small and middle sized factories, the energy losses of mechanical and electric transmission might equal out. The problem of transmission distances could of course also be solved within the frame of mechanical power transmission, for instance by placing different steam engines in the various sections of the factory. Yet, according to the electrotechnicians this would have decisive drawbacks: If these decentral steam engines were supplied with steam from decentral boilers operation would be complicated and the investment costs increased, while if steam was provided from a central boiler, there would be large heat losses in the pipeline system.

Other arguments in favour of electric drive in the cement industry were the reduced repair and maintenance costs of the transmission system, the labour-saving effect of increased automatisation with electric transport machines, and the increased the flexibility of factory design following the replacements of line shafts with electric wires. The journal illustrated the latter issue with several drawings. In the era of mechanic power transmission, cement factories had been designed according to the power flow and not the production flow (figure 2.5a): The most power intensive machines, the slurry grinders and the cement grinders, would be located as close to the central steam engine as possible (very large factories, as mentioned above, might instead install small separate steam engines to provide power to more remote sections of the factory). Electric power transmission, by contrast, made possible group drive (figure 2.5b) or even individual drive (figure 2.5c), and thus a factory design that followed the rationality of the production flow. Individual drive had the advantage of optimal control of the individual machines and reduced mechanical transmissions to a minimum; yet, it had the disadvantage to group drive that it was not always possible to install the motors in dust-isolated rooms, which made casing of the motors necessary, as cement dust was omnipresent in early twentieth century cement factories.

Electric power systems in Danish cement factories

In practice, Danish cement factories had already introduced electric drive immediately after the turn of the century - prior to and independent of the agitation in electrotechnical journals. The electrification of the cement factory 'Danmark' at the Limfjorden is illustrative. Electric drive was first introduced in 1903, expanded substantially two years later (when Aalborg Portland bought itself into the enterprise and thereby added a substantial amount of capital), and completed in 1909-10 with the erection of a new electric power station following the conversion to rotary kilns (this was the last cement factory in Denmark to adopt the new kiln technology). The argument was at least partly to improve the economy of power supply, and the final step of establishing a new power station was to facilitate 'complete electrification' of the factory and thereby secure a 'strongly improved power economy.'[59]

Yet, it was not necessarily the application of electric drive in the factory buildings itself that triggered the introduction of electric power. In the beginning of a large expansion and modernization process between 1907 and 1909, Aalborg Portland's Rørdal factory first introduced electric drive to modernize the raw material transport between the chalk and clay quarries and the factory. Whereas the dumping waggons previously had been pulled by horses, now electric locomotives took over raw material transport on these 1 resp. 2.5 kilometres tracks. For the factory, electric locomotives had the advantage over other locomotives that they could be driven by uneducated labourers. In the following year, electric drive was also introduced in the actual production process, and a new power plant was erected to supply electric power to new kilns, a new wet-process preparation department, a new hardcoal milling department and of course to the electric traction. The large system used 220 volts for distribution, which was converted to 550 volts for the traction system.[60]

By 1910, all seven Danish cement factories had autoproduction systems for electric supply, and all but the Cimbria factory had expanded their autoproduction systems for electric drive. The capacity of these systems largely exceeded that of lighting demand; three cement factories had an autoproduction system with a capacity of some eighty kilowatts, the other three had systems of more than five hundred, eight hundred and eleven hundred kilowatts respectively.[61] Cement factories consequently ranked among the largest electricity producers in Denmark.

Other industries: Flour, beer and paper

Electric lighting in the flour industry

The cases of the dairy and cement industries, then, illustrate how very different contexts of production inspired different motives to introduce autoproduction systems and different technical styles of these systems. Yet these were only two out of many industries that adopted autoproduction systems in Denmark. A briefer discussion of some other industries may further illustrate the point, that the specific context inspired different motives for innovation.

In the flour industry, like in the butter industry, before the First World War electricity was primarily used for electric lighting. The flour branch was split in two types of production sites[62], which for different reasons eschewed electric drive: On one hand, a very large number (more than two thousand) of small rural mills relied on wind power (and possibly diesel power back-up) with a small mechanical power transmission system. And on the other hand, few but capital-intensive flour factories in larger and medium sized towns were satisfied with their mechanical transmission systems powered by a large central steam engine, as it increased the reliability of power supply, while the advantages of group or individual drive in flour factories were minimal (see chapter eleven). As a result, electrotechnical observers identified the flour business for its notorious absense of electric drive, complaining that this industry was “perhaps the only occupation, where electricity has not gained wider application.”[63]

With regard to lighting, however, the situation was quite different. From the beginning in the 1880s, electricity was presented as a new lighting source, which could reduce the danger of fire in the flour milling branch. Mills were not only often build out of wood, but also contained inflammable flour dust in the atmosphere, which made the burning down of mills and flour factories a regular event. Indeed, the ‘explosive property’ of flour dust was subject of scientific investigation in for instance Germany and the United States.[64] In electric incandescent lamps, however, the glowing filament was enclosed in a vacuum glass bulb and therefore isolated from the flour dust. If a bulb was broken, the oxygen in the air would cause the filament to burn over and the electric circuit to break, so that it could not start a fire. Also, electric incandescent lamps did hardly produce any heat and would not dry the timber constructions and thereby pave the way for a rapidly expanding fire. While the emphasis thus was upon the fire issue, also other advantages of electric lighting were praised, such as the steadiness and practical use of portable electric bulbs: Gas lights could not be moved as they were attached to a metal pipe system, while petrol lamps could be moved, but were a fire hazard if they tipped over. Finally, electric lighting would be economically feasible particularly in flour factories, where motive power was available in the form of a large and steadily running central steam engine.[65]

An early example of a flour factory adopting electric lightng is the Langebro Steam Mill [*Langebro Dampmølle*], a leading flour factory in Copenhagen. When the factory was modernized in 1888, a small dynamo was attached to main shaft of the factory to supply some fifty steady lamps in the factory itself, another twenty lamps in offices, and a few lamps for outdoor lighting. The system occupied merely six out of the two hundred and twenty horsepowers of the central steam engine, and was praised for its safety and its economy compared to the previous gas lighting system: Electric lighting was said to cost half of the previous gas lighting.[66]

By the turn of the century, electrotechnical firms advertized that electric lighting should be used in 'every modern mill'.[67] Moreover, in the early 1890s the previously mentioned professor Poul la Cour had developed his 'cratostate' to turn the unsteady wind power into a steady power source able to drive an electric generator, and thus paved the way for the introduction of electric lighting in small mills on the countryside. At the beginning of the twentieth century, the issue of electric lighting in small rural mills was indeed increasingly discussed.[68] An example of a rural mill which adopted an electric lighting system in 1904 is the Lydum mill, a water mill combined with a farm near Varde in Western Jutland (figure 2.6). A small two kilowatt dynamo and an accumulator battery were placed in the mill, and produced electricity for some sixty lamps (marked with an 'x' in the figure) in the mill, the attached house, farm and shop, while the court yard was enlightened by two lamps. The system was operated at sixty volts, and was designed to provide some two hours of daily lighting.[69]

Electric light & power in the beer industry

Breweries, like cement factories, had particular motives to adopt electricity both for lighting and power purposes. In 1882 the Old Carlsberg [*Gamle Carlsberg*] and New Carlsberg [*Ny Carlsberg*] breweries in Copenhagen and the Albani brewery in

Odense had been among the very first Danish firms to install electric lighting systems. Like in the cement industries, large breweries had a large artificial lighting demand: On one hand they were operated around the clock, while on the other hand part of the production process occurred in underground fermentation and storage cellars, which always required artificial lighting. Moreover, gas lighting was considered inappropriate in these cellers, as the moist and carbonic acid in the atmosphere eroded the metal gas pipes. It was mainly for this reason that the Old Carlsberg brewery, the largest in the country, installed its first autoproduction system. It included a small (three kilowatts) steam engine for the sole purpose of driving two generators, which together supplied thirty incandescent lamps and three arc lamps. For using the incandescent lamps in the cellars, these could be plugged in at will in some three hundred sockets. The arc lamps provided outdoor lighting. In the early 1890s, however, the brewery decided to build a new system to enlight the entire brewery and remove all traditional lighting sources. Also this system included a separate set of steam engines for lighting purposes only, while the steam was taken from the central steam boiler of the factory. The system had a large internal distribution network with a total length of twenty-five kilometers, and supplied some nine hundred incandescent lamps and eighteen arc lamps (figure 2.7). The steam engines and generator were situated in one of the factory's ice producing sections.[70]

By 1910, the *Elektroteknisk Tidsskrift* could observe that 'even very small breweries had introduced electric lighting many years ago.'[71] The same article also observed that the larger breweries in the country by now had adopted electric drive. Breweries for instance used a number of pumps and stirring mechanisms to process the liquid product, as well as cranes and transport belts for transport of raw materials and beer bottles. It mentioned two main motives. Like in the cement industry, the comparatively large distances made mechanical transmission systems rather expensive and implied large power losses. And second, an electric motor for an application for instance in a crane at some distance of the power house would not cost more than a mechanical transmission system from power house to crane, while the main advantage was that the machine only consumed energy when it was in operation. The 'lead motive' to introduce electric drive in breweries, then, also was to improve the power economy.[72]

The increasing importance of electric drive relative to electric lighting may be illustrated with the Tuborg brewery near Copenhagen. In 1900, the brewery had installed an autoproduction system powered by two eighty kilowatt dynamos. The demand was just over a hundred kilowatts, mostly for more than eight hundred incandescent lamps (49 kW), nineteen arc lamps (19 kW) and to a lesser degree for nineteen motors (46 kW). By 1915, however, it used two dynamos gathering a capacity of eight hundred and fifty kilowatts, and the motor load dominated completely: Of the demand of nearly fourteen hundred kilowatts, more than two hundred electric motors accounted for more than eleven hundred kilowatts, while more than thirty-six hundred lamps accounted for the rest.[73]

Electric power in the paper industry

Finally, although electric lighting also preceded electric drive in the paper industry, this industry is of particular importance as it would become a large producer of electric power, which compared to the cement industry in terms of output. The paper industry resembled the cement industry in several ways; like the cement industry, it was characterized by a concentration of production in few but large factories dominated by a cartel - the firm United Paper Factories Ltd. [*A/S De Forenede Papirfabrikker*]. In the period from 1900 to 1960, there were between ten and fourteen paper factories in Denmark. And like the cement factories, paper factories were large factories situated outside urban areas, in this case near streams and rivers providing the necessary water for the production process.[74]

The motives for introducing electric drive, however, only partly were the same, following a rather different production process. The actual production process contained three basic stages. First, the raw material (rags, waste paper or cellulose) was cut and mixed by a rotating chopping machine into a pulp of fibres and water (with a water content of some 99%). Second, a paper machine would intermesh the fibres into a paper sheet. To this purpose, the fibre pulp was first projected on a wire mesh belt, where the fibers intermeshed and part of the water was drained. The pulp was then projected upon a felt belt and led between a set of pressure rollers, consolidating the web and pressing out more water. Finally, the paper sheet (still containing 66% water) was fed through a number of heated rollers and thereby dried (to a water content of some 3-6%). And third, in a final section the paper sheet was cut and received additional treatment according to paper type and desired quality. Fine paper qualities, for instance, passed through special roller stands for extra smoothening. Paper factories thus demanded plenty of rotary action for the choppers in the preparation department, the paper machines (basically consisting of revolving rollers either carrying transport belts or pressing the pulp) and the final roller stands. In addition, there were transport machines and water pumps.

During the 1890s, the international attention on hydropower transmission (see the next chapter) also brought electric drive on the agenda of the paper industry journals. Being situated near rivers and streams and often having experience with hydro turbines, paper factories seemed particularly well suited to adopt this technology, as paper factories in for instance Austria, Sweden and at Niagara Falls in the United States illustrated.[75] In Denmark, however, hydropower resources were modest, and the *Elektroteknisk Tidsskrift* found several other reasons why electric drive was well-suited for paper factories.[76] Like in the cement industry, this included the large size of the factory, which would make mechanical power transmissions costly and difficult. And like in the beer industry, this included the possibility to turn off idle machines and save on power consumption, such as the chopping machines of the preparation department, and the possibility to adopt a wide variety of transport machines, such as electric cranes attached to the ceiling carrying the wood pulp to the preparation department of the factory.

However, other important advantages followed the peculiarities of the paper production process. Thus, electric drive would improve the quality and quantity of paper making due to the superior steadiness as well as regulability of electric motors. Contrary to hydro turbines in particular, electric motors of certain types could yield a steady power supply to the paper making machine under changing loads; and although it was possible to regulate the drive speed in mechanical transmission systems, this involved fragile (in reliability and durability) gearing and shafting compared to the superior control of electric motors. The increased steadiness and regulability of electric drive, then, improved the paper quality by producing paper of a more constant weight and thereby increased homogeneity. Besides a quality criterion, this was also an important economic factor, because irregularities in the paper sheet would have to be cut out subsequently and hence cause paper losses. Ultimately, such irregularities could cause the paper sheet to crack, and the entire machine would have to be stopped. Thus, the reduced risks of irregularities and cracks in electropowered paper machines allowed considerably higher production speeds and thereby increased the productivity of the factory. A similar argument applied to the the rollers in the finishing department: Also these would benefit from the optimal power regulation, which electric motors could provide: The traditional belt driven roller stands normally had two speeds only, a low starting speed and a higher operating speed. The change from one speed to the other involved a significant risk of breaking the paper, which made regulable electric motors indispensable.[77]

In practice, by 1910 most larger Danish paper factories, including the factories of the firm United Paper Factories, had autoproduction systems with capacities of several hundreds of kilowatts and were adapted for electric drive.[78] As a leading engineer of the United Paper Factories described in retrospect, in the beginning the economy and reliability of electric power transmission motivated electrification, not in the least as electric power transmission facilitated a centralization of power production instead of operation with decentral steam engines in large factories. At a later stage, the concerns of increased quality and productivity were added.[79] An example was the newly established Ravnholm paper factory North of Copenhagen in 1907. Established to break the near monopoly of the United Paper Factories, the Ravnholm factory represented state of the art technology, and was described by a

German paper journal as one of the most modern paper factories in the world.[80] From the central steam engine, power was transported mechanically to the preparation section, while the paper making machine and the finishing section were supplied electrically.[81] Incidentally, the attempt to compete with the United Paper Factories failed, and the latter soon bought and dismantled the factory.

The increasing importance of decentral drive for the productivity of paper factories is also illustrated by the introduction of unit drive in the paper machines. The paper machine of the Ravnholm factory had been powered by two electric motors. Later, paper factoris provided each roller in their paper machines with its own electric motor. In this way the speed of the paper could be optimized, that is, the tension of the paper sheet in each section of the machine could be regulated between narrowly specified boundaries. In addition, automatic regulation could correct even minor speed changes in particular sections. Illustrative is the combined paper and cardboard making machine in United Paper Factories' new factory in Copenhagen in the early 1930s, which contained no less than fourteen electric motors. In this case, it was estimated that the application of electric drive in each section of the paper making machine might improve its power efficiency by a factor two, while also the production speed could be further increased without cracking the paper sheet.[82]

The diffusion process of autoproduction systems for electricity supply in Denmark, in sum, did not result from the engagement of one single actor group with specific concerns, but involved a large and heterogeneous collection of actor groups. There were large groups of actors with small lighting systems, and also quite small groups of actors with very large systems, which represented most of the autoproduction capacity. The motives for innovation might vary from group to group, that is, primarily from industry to industry: Electric lighting was particular attractive in butter factories because it improved hygienic conditions, in flour mills because it reduced the danger of fire, in breweries because it provided reliable artificial light in fermentation and storage cellars, and in cement factories because high intensity arc lamps facilitated nightly labour outdoors at the chalk quarries. And electric drive was attractive in cement factories because it reduced power losses of large mechanical transmission systems and facilitated electrification of the raw material transport, in breweries also because in a system of electric single drive idle machines could be turned off, while paper factories added the concern for a more homogeneous product quality and higher production speed following the use of regulable electric motors. Butter factories and flour mills, finally, were not yet interested in electric drive at all.

As a result of these motives and the often advantageous conditions to autoproduce electricity, such as availability of cheap steam power or a large lighting (or power) demand resulting in a large annual running time of the system, the number of autoproduction systems indeed rapidly increased to some eight hundred systems by

1910. Moreover, in the following decades the number and output of autoproduction would continue to rise; this development is analysed in chapter six on the consolidation of autoproduction systems.

3
Local systems

Developments abroad

By the time local electricity supply was introduced in Denmark in the early 1890s, it had become a fairly well-known and well-developed technology abroad. Already in the late 1870s Thomas Edison had brought up a vision of a scale increase in electricity supply in the United States.[1] In 1878 he publicly announced that he had solved the problem of 'subdivision of light', that is, to produce more lights from a single supply system. Whereas previously the supply of ten electric lights by a single generator had been regarded 'a triumph of scientific skill', he claimed to be able to produce thousands of lights from a single generator. In his view, this great increase in the scale of electricity supply would make possible the supply of entire lower Manhattan with electric lighting, power and heating to from a single generating station.[2] Soon after he reported to be working on a system of underground distribution from central generating stations in great cities, so that electric light could be supplied to private houses and substitute gas burners at low costs; his central station technology would be able to 'light all houses within a circle of half a mile.'[3]

After this proclamation, which received wide public attention and thus helped to raise funds for the necessary research, Edison and his collaborators developed a technological and organisational basis for local system supply. As Hughes (1983) has demonstrated, the Edison system consisted of a set of interrelated technologies. Firstly, it included a distribution network where the individual lamps were connected in parallel instead of in series, as had been usual. Contrary to serial connection, the number of lamps in the system of parallel connection could be greatly increased without increasing the total resistance. Moreover, each lamp could be individually switched off without interrupting the entire circuit. Secondly, as a consequence of this technical choice, Edison's system included a new type of incandescent lamp; whereas serial connection had demanded low resistance lamps to reduce the total resistance of the system, Edison's parallel connection required high resistance lamps (one hundred ohms) to limit the current in the mains and thereby the costs of the distribution system. And finally, it included an improved type of generator with a low internal resistance to match the low external resistance following from the parallel connection of the load.[4]

In addition to this technical system, Edison and his partners created an organisational structure to exploit the technical possibilities commercially. On one hand, they founded a parent company (the Edison Electric Light Company) to fund research and development and sell patents, as well as subsidiary companies to produce and sell equipment (such as the Edison Lamp Works and the Edison Machine Works). And on the other hand, once it was calculated that the business of supplying electric lighting to consumers at the prices of gas supply would yield a profit, they also founded subsidiary companies to build and commercially exploit electricity supply systems under licence from the parent company. The first of such electric utilities, the Edison Electric Illumination Company of New York, built and exploited the first local supply system in the United States on Manhattan. Finally, as the distribution network of the local electricity supply system was to follow and cross local roads, the utility had to obtain approval from the local authorities in the form of a concession.[5] In Edison's organisational model, then, a private utility owned by an electrotechnical equipment manufacturer operated a local system on a concession of the municipality. When the utility opened the New York system in September 1882, it supplied more than eighty different consumers with low voltage (110 volts), direct current electricity from a central power station. After two years, supply had increased to more than five hundred consumers with some eleven thousand lamps.

By then, however, Edison had already demonstrated his system at the first international electricity exhibition in Paris of 1881, which also displayed the plans for the New York project. Boosting Edison's commercial enterprizes in Europe, the display also advertized the general idea of commercial electricity supply to the public. And, as British historians have pointed out, already in early 1882 several electric utilities in Great Britain had started to connect private consumers to their street lighting installations and thereby created actual local electricity supply systems.[6] Like the New York system, these systems were built and run by private companies (on contracts with local governments) which also supplied the equipment, thus hoping to profit from both activities. Thus, the Siemens Brothers & Co. - the English branch of the large German electrotechnical manufacturer - expanded the street lighting installation in the small town of Godalming in Surrey to private consumers. Likewise, the firms Hammond Electric Light Company (selling and installing American Brush arc lights) and Crompton & Co. (an English electrical manufacturer) established such systems in Brighton and Norwich, respectively. Finally, the English Edison company could open a 'copy' of the New York system at Holborn Viaduct in London, which in fact opened several months before its American counterpart.

During the 1880s, the technology of local electricity supply was also introduced on the European continent, starting in 1883 with the cities of Milano in Italy and Rotterdam in the Netherlands. Moreover, local electricity supply systems were introduced in Denmark's neighbour countries: In Germany, some fourteen systems had been established by 1888, including systems in large cities as Berlin (1884, 1885) and Hamburg (1888). And in Sweden, towns as Gothenburg (1884) and Örebro

(1886) introduced electricity supply to the public.[7] The diffusion of local electricity supply systems, however, did not accelerate until the 1890s. In Great Britain, for instance, early public electricity supply had suffered several set backs in the 1880s (the Godalming and Holborn Viaduct systems were closed down as the municipalities preferred gas street lighting), and first in the 1890s local electricity supply spread to the larger province towns. Only after 1897 the diffusion process accelerated with 'a very large extension of electricity supply stations'.[8] And in Germany, the establishment of new public electricity supply systems increased from several dozins of systems annually during the first half of the 1890s to more than one hundred new systems annually during the second half of the decade.[9] This made Germany a leading country in the field of public electricity supply in Europe, and thereby the primary country of reference for Danish engineers.

The idea of local electricity supply in Denmark

Public electricity supply in the technical press

In Denmark such actual local electricity supply systems were not established before the early 1890s, although some autoproducers had taken up a limited supply to other consumers.[10] Still, during the 1880s the very notion of public supply was gradually developed from an exotic rumour to a serious concern. This development is reflected in the technical press as well as in the considerations of important actors with regard to the concrete introduction of local systems, such as the first electrotechnical firms and the municipalities.

It is not surprizing that Edison's early visions of electricity supply to the public were enthusiastically received in the popular press. From 1878 onwards Edison's name was frequently mentioned, and a report from the 1881 Paris exhibition proclaimed that the period of incidental application of electricity was probably over; from now on, electric lighting would become 'the common good of nations.'[11] Engineers, however, were more cautious. This can again be illustrated by the addresses and discussions on the issue in the Technical Society - before the establishment of the Society of Danish Engineers [*Dansk Ingeniørforening*] in the 1890s the most important forum of discussion for technological matters. For instance, in his address on the status of electric lighting in 1878, military engineer V. E. Tychsen used only little space on Edison's claims; he found it 'highly unbelievable' that Edison could supply thousands of lamps from a single generator, and thereby provide 'most of New York' with electric lighting, electric heat for kilns and stoves and electric power for sewing machines - up to ninety-five times cheaper than by conventional means. Still he knew Edison as a famous inventor, who had repeatedly surprised the world, and hoped that at least 'a tenth' of his claims would be realized.[12] Likewise, when Tychsen reported from the Paris exhibition three years later, he treated Edison's new incandescent lighting system merely as one out of many. Contrary to the popular press, he did not regard its technical and economical feasibility sufficiently proven; on the contrary, this was a task for the many research projects going on abroad at the moment, and made Edison's New York system important as a pilot project.[13]

The tune changed, however, after the New York system had been operational for a couple of years and thereby had proved its technical feasibility. For instance, in his address to the Technical Society on the state of the art of electric lighting in 1884, military engineer C. Juul heralded Edison as the person who had first recognized the 'large advantages' of public electricity supply, embodied in the technically successful New York system. According to Juul, public electricity supply was 'the last and perhaps most important development in electric lighting.'[14] Still, with regard to economy he found the competitiveness of electric lighting far from proven. Most articles supporting the new technology lacked an empirical base, and indeed Edison's New York system itself seemed to be economically stagnant. On the other hand, this might be due to the patent fees it paid to the parent Edison company, the size of which was kept secret. Moreover, Juul reckoned that public electricity supply systems undoubtedly would be able to supply electricity cheaper than autoproduction systems, since the exploitation costs per lamp decreased with an increasing amount of lamps in the system. In a final comment to Juul's address, the chairman of the society shifted focus to Denmark by suggesting that public supply on a sufficiently large scale might be economically feasible in the Danish capital, Copenhagen.[15]

In the second half of the 1880s the issue of local electricity supply was increasingly put on the agenda. The Technical Society even arranged a prize essay on the subject. In his published contribution, engineer Zahrtmann went a step further than his predecessors in discussing the economy of public electricity supply by working out a detailed example of such a system for the provincial town of Horsens. Departing from the current gas consumption in this town, he calculated that a local electricity supply system with a similar capacity would demand a power station with a capacity of some 180 kilowatts. He suggested to place the power station at the harbour to facilitate cheap supply of hardcoal, and discussed various forms of distribution networks before embarking upon detailed economical calculations. These showed, however, that the expenses of electricity supply still were about twice as high as those of gas lighting per unit of lighting energy provided. This was mainly due to the combination of high investment costs and a low running time of electricity supply systems, which possibly run only a couple of hours per day and thus would take relatively much time to repay the investment. Not until this running time was increased to some ten hours per day, electricity supply would be fully competitive with gas supply.[16]

Although Zahrtman's investigation explicitly focused upon the economy of electricity supply, he , like authors before him, also stressed the qualitative advantages of electric lighting to gas lighting - of not polluting the air, not heating the room in which it was used, not being a fire hazard, and being 'rather beautiful'. As the journal of the Technical Society could report, these qualities might make electric lighting attractive for the public despite lower gas prices. For instance, the new electric utilities in the German cities Berlin and Hamburg rapidly attracted consumers, despite the fact that also here electric lighting cost about twice as much as gas lighting.[17] The time therefore seemed ripe for the introduction of local electricity supply in Denmark.

Electricity supply as a municipal concern

Parallel to this discussion in the Technical Society, the issue of public electricity supply was taken up in few large municipalities. The initiative normally stemmed from private actors - individuals or firms, which brought the issue to the attention of the municipality. For example, directly following the 1881 exhibition in Paris two Danish participants presented a printed report to the municipal council of the large provincial town of Odense, predicting a grand future for incandescent lighting.[18] And in Copenhagen, the issue was placed upon the municipal agenda with the first application for a concession to exploit a public supply system in the city, which was sent in by architect Johan Stillmann, who had recently returned from abroad. Stillmann added a supply scheme, in which a central generating station would supply several large consumers such as theatres, the railroad premises, the Industrial Society [*Industriforeningen*] and the Tivoli. If his pilot system was successful, Stillmann hoped to obtain a monopoly to supply electricity in Copenhagen.[19]

The following discussion on the issue in Copenhagen has been decribed in detail, and allows for a closer investigation of the status of electricity supply within this municipality in the 1880s.[20] Notably, Stillmann's application for a concession was only the first of a number of similar applications, filed occasionally by small groups of citizens seeking to operate a small system to supply their business offices, but also by representatives of Danish and foreign business life, which forced the municipality to a more careful response. These applications included one by a partnership of directors of four large Danish firms - including Denmark's largest machine works and ship yard Burmeister & Wain - to supply the inner city with electric lighting (1884), as well as one by director S. C. Hauberg (1886), whose recently established firm was one of the first signs of an emerging Danish electrotechnical industry. Finally, also director Emil Rathenau of the large German Edison Company [Deutsche Edison

Gesellschaft, the predecessor of AEG], whose subsidiary company run the Berlin system, was in Copenhagen to negotiate the establishment of a local system (1887) and finally applied for a concession together with Hauberg.

None of these applications, however, was rewarded by the municipality. Still in 1884, both technical experts of the municipality - the city engineer and the director of the (gas) lighting service - found the technical state of electricity supply poorly developed, and doubted if there was any actual need for a public electricity supply system in the city. Electricity might be attractive for a few large consumers, but these could invest in an autoproduction system. The applications for concessions were accordingly rejected or withdrawn. However, the technical experts adviced the municipality to prepare rules for the introduction of public supply, which might gain future importance for the town citizens. In particular, they recommended the municipality to formulate conditions for a concession to private companies, to, as director Georg Howitz of the lighting service put it, "prevent abuse or improper profits by private enterprise".[21] Such conditions should be modelled after the contract between the municipality of Berlin and the German Edison company, which included municipal control with electricity prices, an obligation of the utility to supply any consumer in the supply area who agreed to the supply terms, the right of the municipality to purchase the system after ten years of operation, and finally an annual fee to the municipality relative to the turnover and the profits.[22] Motivated by the increasing amount of applications it received, the municipality did take up this matter and worked out such concession conditions, which were accepted by the municipal council in 1887. Although critics interpreted the concession conditions as harsh and close to a prohibition, which would scare away most applicants, Hauberg's firm did notify the municipality that it was willing to accept them.

By then, however, the issue of public electricity supply was under revision within the municipality itself. Inspired by the success of the technology abroad, it followed the technical press in promoting public electricity supply from a peripheral issue to an important concern. Again the city's technical experts were at the basis of the attitude of the municipality. Thus it was lighting service director Howitz, who strongly recommended the municipality to establish a public supply system of its own in 1888. Indeed, he even submitted his own electricity supply scheme to the city magistrate. His argument for placing the issue centrally on the municipal agenda was that electricity supply, like municipal water and gas supply, might be a profitable enterprise and as such should be run by the municipality. Moreover, the establishment of autoproduction systems by large lighting consumers might damage the gas sales; to keep these consumers as customers of the municipality, the establishment of a municipal electricity supply should have top priority. Requested to comment Howitz' argument, the city engineer completely agreed. When the city magistrate ordered a more detailed study of the options for electricity supply, public electricity supply had indeed become a central point on the municipal agenda.[23]

The first Danish local electricity supply systems

Few years later, the first local electricity supply systems were established in Denmark: In 1891 such systems were established in the provincial towns of Køge on Zealand and Odense on Funen, while Copenhagen followed in 1892.[24] Notably, these systems were introduced by different kinds of actors. The local system in the small town of Køge was started and operated by a local watchmaker, who had previously demonstrated his technical enthusiasm by establishing a small telephone system operated from his dining room. With his recent experience from the installing of an autoproduction system at the local dairy, he repeated this strategy by establishing a small local electricity supply system, the power station of which was based in his cellar, and supplied lighting to shopkeepers for several hours in the evening. Technically, the 'central station' consisted of a gas engine and a dynamo, which fed a small low voltage distribution network. Notably, the system operated without a concession from the municipality until a new power station was built in the mid 1890s, and remained in individual ownership until the late 1940s.

The system in Odense, by contrast, was run on a larger commercial basis by the Copenhagen-based firm Danish Electricity Company [*A/S Det danske Elektricitets-kompagni*]. The capital was raised by a number of influential Odense citizens together with Hauberg's leading Danish electrotechnical firm [now merged into *A/S Koefoed & Hauberg*, later *Titan*] and a Danish stockbroker firm. The company held permission from the Odense municipality to use public streets to carry electricity cables for twenty-five years; in return, the municipality received an annual fee from the company, and also reserved the right to purchase the utility after the year 1900. Technically, the power station contained four steam powered dynamos with a supply capacity of some two-thousand incandescent lamps, and some 3.5 kms of external distribution lines connecting some seventy consumers, mostly shops.

In the case of the first local system in Copenhagen, finally, it was indeed the municipality which established and operated public electricity supply from the very beginning. As mentioned above, there was a municipal-economic argument involved. In addition, the city magistrate had ordered a study of the economic results of public electricity supply systems abroad. In the report, engineer Ib Windfeld-Hansen - the future director of the municipal lighting service - stressed that public electricity supply had been introduced in a number of large cities in for instance France, Great Britain, Italy, Switzerland, the Netherlands, Belgium and Sweden. Yet it was

Germany that undoubtedly had taken the lead. Moreover, German electricity supply systems were often established and run by public authorities with good financial results. In this respect it was also important, that (municipal) gas sales were not negatively affected by the competition from electricity, as some might fear, but rather seemed to increase.[25] This financial profitability convinced the city magistrate, which in turn convinced the municipal council to accept the proposal and actual design of its lighting service director.[26] That the municipality wished to profit from the supply business is also indicated by the critique in the local press, accusing the municipality to take 'pharmacy profits' of thirty-three percent of the gross income of electricity supply, as it also did with the gas supply. Thereby, according to this critical press, it revealed its primary interest in the municipal budget rather than in the welfare of its citizens.[27]

With regard to the technological choices, the capacity of the power station was set at twenty thousand lamps. This was achieved with a generating capacity of 930 kilowatts, produced by three steam engines with two directly connected dynamos each and a supporting accumulator. For electricity distribution, the utility had to choose between local supply with low voltage, direct current distribution, and district supply involving high voltage, alternating current transmission, which by now also had been developed to a practical stage abroad. It was decided to follow Windfeld-Hansen's recommendation of local supply: The advantage of district supply of economic electricity transmission was outweighed by disadvantages as its leathal danger (both due to the high voltage and due to the alternating of the current, which causes the human muscles to cramp), the difficulty in isolating the high voltage wires, its more difficult regulation, the energy losses in the transforming process (from low to high voltage and vice versa) and the lack of a practical alternating current motor. When the Copenhagen system was inagurated in 1892, it resembled the early Edison systems in New York, London and Berlin in steam powered generation and direct current distribution at 110 volts, which was sufficient to supply consumers up to one kilometer from the power station (figure 3.1).[28]

The actors of local systems

The diffusion period of local electricity supply systems in Denmark can be roughly located between the mid 1890s and the 1920s. On one hand, existing systems were expanded. In Denmark's only truly large city, Copenhagen, such expansion was not only achieved by increasing the capacity of the inner city system, but also by establishing two more local systems to supply the rapidly expanding quarters surrounding the inner city (inaugurated in 1898 and 1902 respectively).[29] And on the other hand, the local system first slowly and then explosively spread over the country. Before the turn of the century, local supply systems were established only in another six provincial towns. From then diffusion slightly accelerated, and the first published listings of electricity supply enterprises reported more than forty local systems by the end of 1905 (table 3.1). After 1905 the diffusion process accelerated rapidly: During 1906 the number of local systems doubled, and during the following years some thirty-forty systems appeared annually. By the end of 1910 there were nearly two hundred and forty local systems, by the end of 1915 nearly four hundred - despite the fact that larger towns had begun to abandon local supply systems to the favour of district systems (figure 3.2). During the First World War the diffusion process slowed down, and the number of local systems stabilized at some four hundred and thirty systems in the early 1920s.[30]

Who, then, were the actor groups responsible for the diffusion of local electricity supply? Firstly, an analysis of the available listings shows that most early systems were established and run by private capital. Thus, only a small fraction of roughly 10% of the local systems in 1905 were owned by a municipality. Besides the system in Copenhagen (1892) this included systems in the provincial towns of Kolding (1898), Århus (1900) and Ringsted (1902). By contrast, almost half (48%) was owned by a private entrepreneur, some 17% by a co-operative society of the consumers, some 14% by a limited company and some 12% by a partnership. Yet, as the text following the listing specified, the actual distinction between these latter ownership forms could be rather vague. In particular, many limited companies and partnerships closely resembled co-operative societies, as they included practically all consumers in the area. In addition, in several cases there was a mix of private entrepreneur ownership and co-operative consumer ownership; in such cases, a private entrepreneur might own the engine, while a co-operative society owned and exploited the electric part of the system, that is, the generating equipment and the distribution network.[31]

With the acceleration of the diffusion process, however, this situation changed. Indeed, two actor groups increasingly came to own the urban and the rural systems respectively. A distinction between 'town systems' and 'village systems' according to the demarcation used in the Danish electricity supply statistics after 1923 may illustrate this point. In these statistics, town systems are demarcated from village systems as settlements with 'an urban character' and more than one thousand inhabitants. Although the boundary in this demarcation seems rather arbitrary, it avoids treating settlements after their administrative status, which is problematic because a number of so-called 'villages' - often those which had been connected to the railways in the second half of the 19th century - had rapidly expanded during the beginning industrialization and urbanisation processes. By the early twentieth century, they might be considerably larger than smaller 'market towns', as settlements with township rights were called (an administrative status, which despite its reduced practical importance was not abolished until 1970).[32] Under any circumstances, application of the former demarcation criterion to the available surveys of electricity supply systems provides an instructive picture of the actor groups responsible for the diffusion process of local electricity supply systems (table 3.1).

Table 3.1: Ownership of local town and village systems in 1905-1923[33]

		Municipal	Private entrepreneur	Limited company	Co-operative society	Partnership	Other/?	Total
Town systems	1905	5	15	5	1	1	-	27
	1910	34	7	8	1	3	1	54
	1915	46	4	7	3	4	1	65
	1923	45	2	5	13	6	-	71
Village systems	1906	-	4	1	6	4	1	16
	1910	1	37	11	99	22	7	177
	1915	-	-	-	-	-	-	324
	1923	4	45	17	264	27	1	358

With regard to towns, the acceleration of the diffusion of local systems from 1906 coincided with the rapidly increasing role of the municipalities at the expense of that of private actors. By 1910 some 63% of the local systems in towns were municipally owned, by 1915 70%. During the last phase of the diffusion process the figure again decreased to 63%, following a significant rise of the number of co-operative societies (18% in 1923). However, this does not signify a change of ownership, but is due to the demarcation criterion used: While on one hand large municipal utilities changed local supply for district supply, on the other hand several villages, supplied by co-operatively owned utilities, grew into small towns as they crossed the boundary of one thousand inhabitants. Thus, the dominion of municipal ownership is even clearer among towns with, say, more than five thousand inhabitants: In 1915 less than half (twenty-nine) of the local town systems were situated in such larger towns, and 90% of these were municipally owned. By contrast, of the remaining local systems in smaller towns, only 56% had municipal ownership. Also in 1923 nearly 90% of the local systems in larger towns were municipally owned, while the figure for systems in smaller towns had decreased to 51%.[34] It may be concluded, then, that the diffusion of local systems in towns followed the massive involvement of the municipalities, which from 1906 established almost all new systems and occasionally took over existing ones.

With regard to village systems ,the co-operative society increasingly became the most important ownership form. While other ownership forms still dominated at the initial stage of the diffussion process, by 1910 more than half of all village systems were co-operatively owned. And by the early 1920s this figure had increased to three quarters. In addition, as mentioned above, a number of other ownership forms might in practice closely resemble the co-operative society: Partnerships and limited companies might include all consumers in a village as partners or shareholders, while entrepreneur ownership might be combined with strong consumer influence. As also the utilities in many small towns - which generally saw themselves as part of rural rather than urban Denmark - were organized as co-operative societies, consumer associations certainly were the main actor group responsible for the diffusion of rural local systems.

From actor to non-actor: Private enterprise and town systems

Before turning to the actor groups of municipalities and consumer associations, however, the role of private enterprise in town electrification deserves some attention. For private enterprise was not only responsible for the introduction of local systems in its earliest phase; it also remained a key actor in other countries than Denmark - perhaps most strongly in the United States. What happened, then, to the engagement of this actor group in Danish town electrification?

A change in motives for engagement in the electricity supply business during the diffusion period is only a partial answer. Prior to 1906, leading motives for private actors to establish and exploit public electricity supply systems were the expectation to derive a profit from the public electricity supply business as well as the concern to make electricity available to the local community. An example of the profit motive is found in the provincial town of Slagelse on Zealand, where a local system was established in 1893. In the negotiations with the municipality on a concession, the applicant - a book-keeper of the local distillery - motivated his project by his expectation to derive a profit from the electricity supply business. To this he added that members of the trade and larger industry community had complained over the gas lighting, and desired electricity as a more intense and pure source of light; finally, he referred to the benefit for the town if it obtained a competitive advantage to its neighbouring towns.[35]

Only occasionally did the emerging Danish electrotechnical industry involve in the establishment of electric utilities, thereby profiting both from electricity supply and the sale or installation of equipment - the combination that proved so successful for Edison's company (later: General Electric) in the United States and also the German Edison company in Germany. The Danish electrotechnical industry hardly compared with these foreign giants, however, which may partly explain its modest engagement in public electricity supply.[36] Still, there were examples of such engagement particularly in the early phase. For instance, the Danish Electricity Company, ltd. which established and ran local systems in Odense and Ålborg, did represent the young electrotechnical industry in Denmark as mentioned above. And in Vejle, the installation firm Kemp & Lauritzen participated in the financing of the first local system.[37]

Finally, the motive to make available the new lighting and later power source to the local community is particularly visible in the case of the Northern-Jutland market town of Frederikshavn, where a local system was established in 1900. Here the initiative stemmed from a local pharmacist, a bookseller and a chartered surveyor, who in collaboration with the German electrotechnical firm Gebr. Körting applied for a concession on behalf of a consortium of seventy-eight citizens. The citizens then jointly established the Frederikshavn electricity company, ltd. [*A/S Frederikshavns Elektricitetsværk*, 1899], an example of adopting the co-operative idea in market town electricity supply.[38]

Only when the municipalities massively engaged in urban electricity supply from 1906, the latter motive became less important. Instead of establishing a supply system themselves, influential citizens or local interest organisations - particularly of local industry and commerce - would increasingly press the municipality to make electricity available. The example of Nykøbing on Falster is instructive. Here, a local steam miller had in vain applied for a concession to exploit a local system in the mid 1890s, and then established a block station (a local system supplying only a block of houses) instead. Yet he continued to work for a larger public supply system in the town, and in 1905 he teamed up with other local industrialists to agitate for a municipal system. Using their political influence, these industrialists first got political parties to place supporters of municipal electricity supply on their electoral lists. After the municipal elections, they pressed on the new council for further action; they actually visited a new member, and future chairman of the municipal electricity committee, in his office to remind him that he 'had been elected to carry through the electricity cause', and urge him to hurry up the project. A municipal system was indeed established shortly after.[39]

The profit motive, by contrast, did not disappear. Before the municipalities decided to exploit the supply of electricity themselves, there was often a 'continuing stream' of concession applications from private entrepreneurs and companies.[40] The failure of private actors on the electricity supply field, then, was primarily a result of their rejection by the local authorities. The motives of the municipalities to do so will be investigated below. Yet it is remarkable that many decisions to erect municipal systems were directly provoked by a concession application from a private firm. In Randers, for instance, the municipality had rejected private concessions from the mid 1890s, including one from the Danish Electricity Company, Ltd. For although the municipality agreed that a public supply system might benefit the town, it was reluctant to give a concession to a private firm. On the other hand, the municipal council could neither agree upon the establishment of a municipal system, and the matter was postponed repeatedly. Finally, when a new application for a concession put the matter once more on the municipal agenda in 1904, the municipality decided to reject the application and erect its own system.

Other examples include the provincial towns of Fåborg on Funen, Nykøbing on Mors and Rudkøbing on Langeland. In Fåborg, the local citizens allied themselves with the Copenhagen division of the German electrotechnical firms *Siemens & Schuckert* and applied for a concession (1904). Forced to respond, the municipality decided to erect its own system, which became operational in 1907. In Nykøbing on Mors, a private applicant was rejected by the municipality in 1899 because his project was deemed 'unrealistic', while another applicant was rejected in 1906 with the argument that if there was to be established a public supply system, it was to be municipally owned. Few years later the municipality indeed did decide to establish its own system, which became operational in 1910. Finally, in Rudkøbing a private application brought the issue back in the municipal council after it previously had investigated the matter in great detail, but decided to expand the municipal gas works instead. Under the threat of private exploitation of a public electricity supply system, however, the municipality decided to quickly establish a municipal system, which indeed was realized within half a year.[41]

Finally, a number of existing private utilities in larger towns were pressed out of the market by the municipalities. The right of the latter to purchase the former was normally specified in the concessions, which often closely resembled the concession terms worked out in Copenhagen and thereby the Berlin concession of the early 1880s. For instance, the concession obtained by the private utility in Slagelse specified the municipal right to purchase the utility after fifteen years of operation. The price was to be set by an independent assessment of the value. In other cases the municipality could purchase the private utility much sooner: In Odense (1891) the term was set to nine years of operation, in Frederikshavn (1900) to only six years.[42] This is not to say, however, that the municipalities actually exercised this right of purchase if they desired to take over the supply business. The Odense municipality, for instance, notified the Danish Electricity Company, Ltd. that it would not exercise its contractual right of purchase, but would build its own system instead. The private utility was furious, claiming not to be able to compete with the municipality on equal terms, as according to its concession the municipality was to approve of its expansions. The municipality thus held a strong position in the following negotiations, which ended with the municipal purchase of the distribution network only, while it built a new power station of its own. In effect, the municipality had paid the private company less than half of the investment value of the private system. The Odense model was followed by the municipalities in Slagelse and Vejle, much to the discontent of the private companies. In Slagelse the company completely refused this solution, but was then pressed by its creditors to comply.[43]

Municipal interests in utilities and electricity

Municipal socialism

What, then, caused the municipalities to massively engage in the electricity supply of Danish towns? To start with, it should be noted that prior to the era of electricity supply, the Danish municipalities had already developed a 'tradition of highly autonomous local administration which easily absorbed new municipal tasks', as Hyldtoft (1994) has put it in his investigation of municipally owned gas works in the nineteenth century.[44] However, this tradition of autonomy was much younger than for instance the tradition of Swedish local autonomy.[45] For the local autonomy of Danish market towns of the middle ages had been largely eroded during the early absolute monarchy, when the King appointed civil servants as local administrators. Instead the municipal autonomy existing in the beginning of the twentieth century was a nineteenth century construction, heavily influenced by economic liberalism with its preference for decentralization, and by the French Revolution with its praise of local democracy. Particularly inspired by the municipal reform in Preussia in 1831, Denmark had been divided into municipalities through the market town Act of 1837 and that of rural municipalities of 1841. With regard to decentralization, already before this reform tasks like poor relief (1803) and education of the children between seven and fourteen years of age (1814) had been legally defined as local concerns, while later several tasks of a decidedly state concern were added (e.g. military tasks and the collecting of state taxes besides municipal taxes). And with regard to the democratic ideals of the French Revolution, these reforms increased the influence of bodies of locally elected citizens. Moreover, with the introduction of a constitutional democracy in 1849, the municipalities were promised full democratic control with internal affairs. This promise was implemented through a set of new Acts in the late 1860s, which gave municipal councils of locally elected citizens a high degree of local autonomy - for instance with regard to the municipal budget. Thereafter the process of democratization took form of a widening of the electorial criteria, until universal suffrage to municipal councils was introduced in 1908. Danish municipalities thus were local and independent units with their own income and expenses under inspection by the ministry of domestic affairs, which for instance set boundaries for increases in municipal taxes.[46]

Moreover, by the turn of the twentieth century these municipalities were already practicing exploitation of utilities, such as gas works and water works. With regard to the establishment of local gas works from the 1850s, early arguments for municipal ownership included the gain of technical expertise and the stimulation of local employment. Later, it might follow the economic theory of practical monopolies - that such capital intensive local utility in practice formed a monopoly (competition between several local gas systems would imply waste of capital) and thus best run by the municipality. Yet the decisive argument for municipal engagement in gas supply was its profitability and the low economic risks, which had been convincingly demonstrated by privately owned gas works. The result was remarkable also in an international perspective: Only fourteen years after the first municipal gasworks had been established in 1856, more than seventy percent of the Danish gas utilities was municipally owned and managed.[47] Also from the 1850s Danish municipalities had begun to establish water works, although their number did not increase rapidly until the late 19th century. By 1906, fifty two of seventy five market towns had their own water works, which were primarily municipally owned.[48]

Finally, the issue of municipal engagement in commercial enterprises was much discussed at the principle level just after the turn of the century.[49] The issue was not in how far municipalities could operate such enterprises better than private actors, but in how far they could run them with a profit so as to obtain an extra source of income for the municipality. The general attitude was that this praxis of 'municipal trading', or 'municipal socialism' as it was known in Denmark, was morally acceptable: It was argued that all municipal activities should be regarded as an economic whole, meaning that the municipality should have the possibility to use a profit from for instance its water or gas works to carry through much needed improvements in schools, expand the police force or reduce high municipal taxes. Moreover, 'municipal socialism' was distanced from the politically controversial 'pure socialism', which rejected the idea of municipalities seeking profits, while on the other hand a number of non-socialists supported it from the point of view that free competition could not solve all problems.

With regard to the kind of enterprises proper for commercial municipal exploitation, the journal for the association of market towns quoted a recent report of the committee on municipal trading under the British Parliament. According to this committee, three preconditions justified municipal engagement in the supply business: First, there should be a juridical or practical monopoly (e.g. traction, gas and water supply), where large investments made competition uneconomical. Second, the product should be widely desired by the public. And third, the enterprise should use public streets and thereby constrain traffic. Obviously electricity supply to the public qualified for these conditions, and by the time it gained importance in Danish towns, commercial municipal exploitation of utilities had become an important municipal concern.

Electricity in the municipal press

This concern for obtaining an extra income for the municipal treasury is also reflected in the way, in which electricity supply was brought up in the municipal press. In the journal for the association of market towns, the issue of public electricity supply was first addressed in the late 1890s. As electricity supply was increasingly discussed in the single municipalities, the chairman of the association invited the Copenhagen utility director Windfeld-Hansen to discuss its importance for Danish market towns. Windfeld-Hansen found this increasing interest 'only natural' in view of the rapid diffusion of public electricity supply abroad and its beginning diffusion in Denmark. Since the Paris exhibition of 1881, which he regarded the starting point of the field, there had been established no less than 375 independent electricity supply systems in Germany, about 120 in Great Britain and about 450 in France (most of which were very small). In addition, in the United States electric traction rapidly gained importance. Finally, also the systems established in the Danish capital and several provincial towns expanded rapidly; his own Copenhagen utility, for instance, had five-folded its supply from the end of 1892 to 1898.[50] Windfeld-Hansen related this success to the qualitative advantages of electric lighting. And with regard to electric power, experience from his own utility (where electromotors might have a very small capacity of one or two horsepower) led him to conclude that electric power was particularly important for the small industries in the market towns. The disadvantage of electric light and power was that it still was more expensive than conventional means of light and power. Still, the price difference had been reduced so far, that the term 'luxury lighting' had become obsolete. Moreover, electric drive would be feasible in industries with a discontinuous or variable power demand, as electromotors were easily started, stopped and regulated.[51]

With regard to the exploitation of a public electricity supply system, Windfeld-Hansen stressed the important relation of electricity supply to gas works; as most larger Danish towns possessed gas works and these primarily were municipally owned and gave a 'significant economic surplus', fear of competition from the new energy source was a well-known municipal concern. Yet he could demonstrate that in Copenhagen gas sales increased at a steady rate despite the success of electricity, not in the least due to its new application in cooking. He could also refer to figures of growing gas sales in a number of German, British and Swedish towns, and thus conclude that this fear was unwarranted.

In sum, electricity supply was presented as of major importance to Danish market towns, although Windfeld-Hansen recommended the municipalities not to establish public supply systems until the economic returns were sufficiently certain; in most cases, this would demand a connection of at least one thousand incandescent lights. On the other hand, he warned the municipalities not to wait too long, thereby stimulating the diffusion of autoproduction systems: He mentioned the development in the German town of Halle, where the municipal obstruction of public supply had resulted in the establishment of more than fifty autoproducers and block stations, thus making it very difficult to later centralize the production in a public supply system.[52]

Although the journal did not follow up the issue, a newly started municipal newsletter kept municipalities informed on the diffusion of electricity supply in Denmark. Moreover, in 1906 it explicitly addressed the issue of economic feasibility of public electricity supply systems in small and medium-sized towns, following a recent discussion in Germany.[53] According to statistics published by the German electrotechnical society, there was a clear relation between the size of the town and the profitability of its electricity supply system. In towns larger than twenty thousand inhabitants, the profitability of public electricity supply was beyond any doubt: Electric utilities in towns of twenty to fifty thousand inhabitants had in average annual gross profits of more than thirty percent of the invested capital, while utilities in towns of more than one hundred thousand inhabitants reached a surplus of nearly ninety percent. Subtracting some five percent for interest on the loans, these were all very profitable operations. But for towns of less than twenty thousand inhabitants, like the majority of Danish towns, gross profits were considerably lower. In towns of less than ten thousand inhabitants the average profits were even insufficient for interest and repayment. In these cases, electricity supply actually was a burden for the municipal budget.

These results, however, had been contested in an alternative study by the German engineer Hoppe, who had excluded from his analysis electric utilities that had only recently started out or were not managed by municipalities or larger companies (which should guarantee proper management). If the sample was reduced in this way, utilities in small towns of one to five thousand inhabitants had an average annual surplus of more than eight percent of the invested capital (or three percent after subtracted interest). Thus, the Danish readers of the newsletter were told, public electricity supply could in fact be profitable also in very small towns. The sample included some utilities operating with a deficit, but these cases could be explained by investment in too expensive power stations, too high wages or too expensive primary

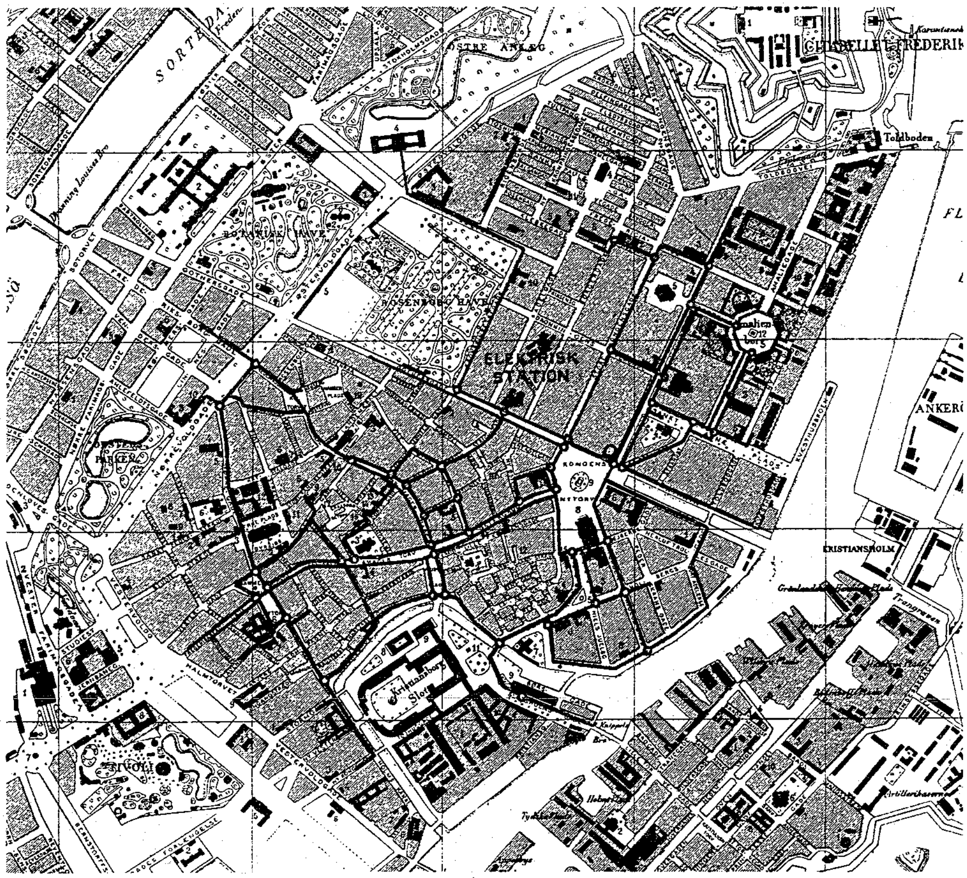


Figure 3.1: The first local electricity supply system in Copenhagen (1892). Source: Rode 1942, inserted between pp. 192-193.

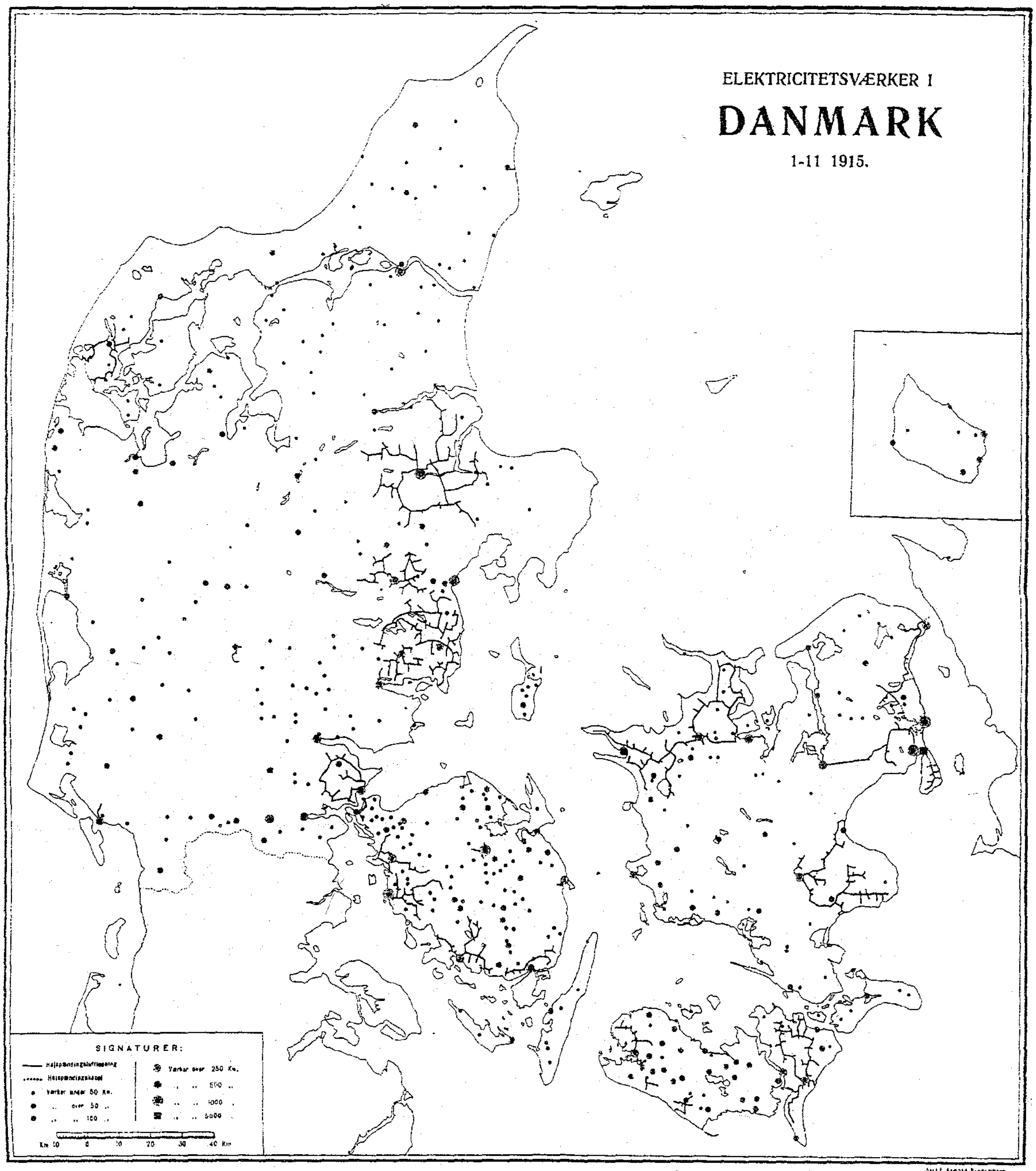


Figure 3.2: Public electricity supply systems in Denmark in 1915. Local systems are represented by points (distribution networks are not plotted in), district systems by power stations with high voltage transmission lines. Source: Appendix to Elektroteknikeren (1915)

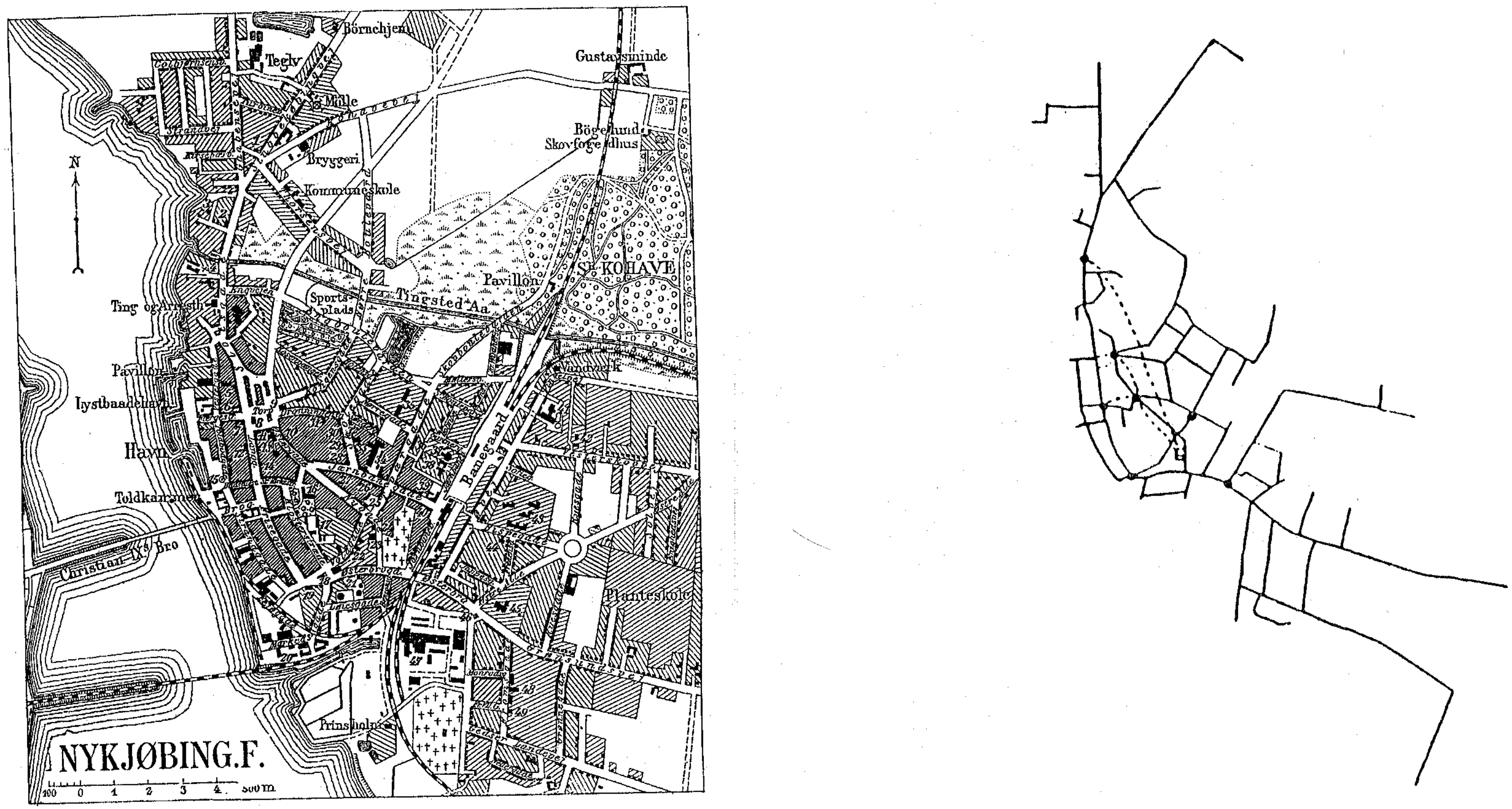


Figure 3.3: Map of Nykøbing Falster, including the power station opposite to the churchyard at the 'Nygade' street (23), and the low voltage, direct current (2 x 110) distribution system in 1915, with a maximal supply distance of two kilometres from the power station. Sources: Salmonsens Konversations leksikon XVIII, 293 and Wollesen 1957, 78.

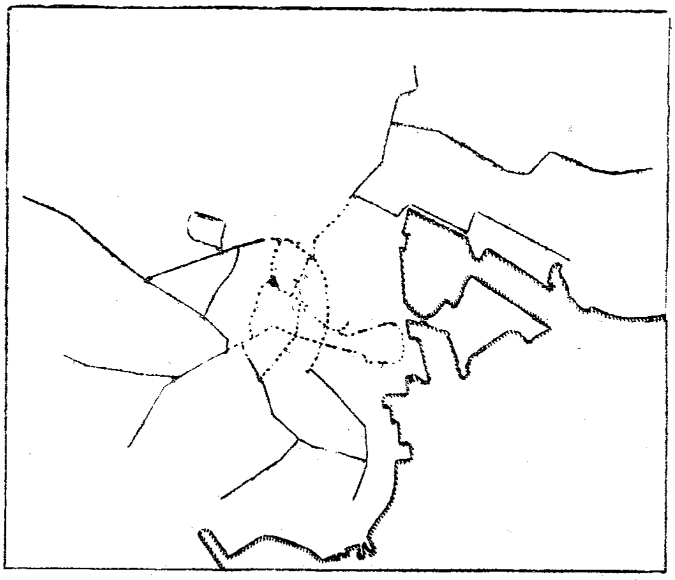


Figure 3.4: The low voltage, direct current distribution system of Svendborg in 1906. Source: Wollesen 1957, 78.

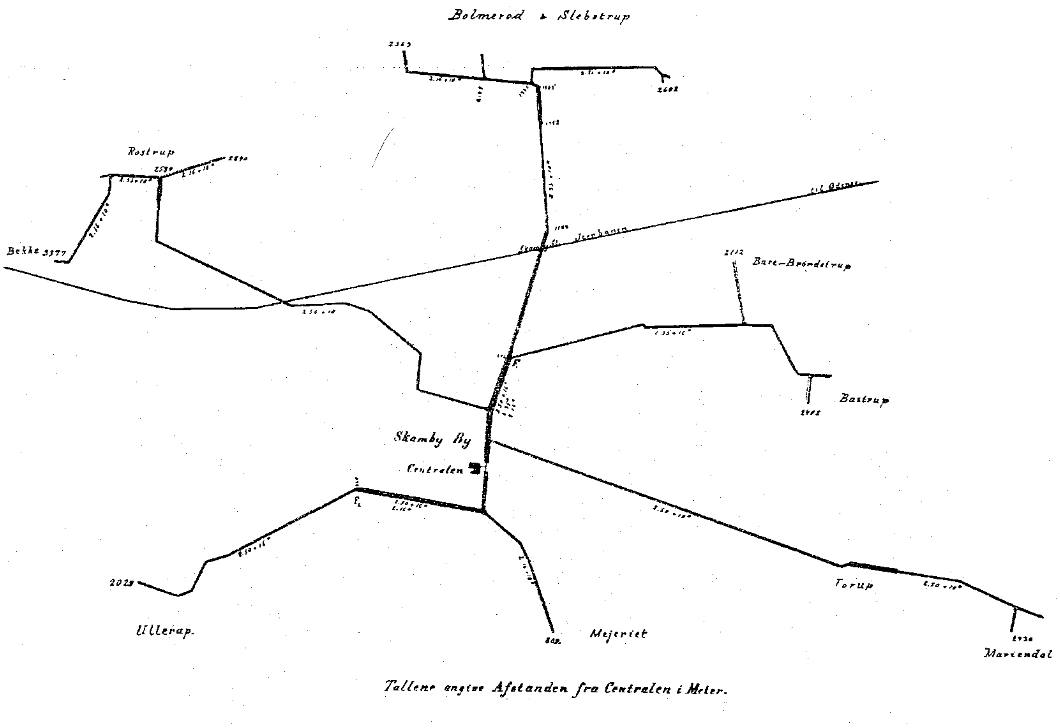


Figure 3.5: The large rural local system of Skamby, supplying the main village and eight other small villages, the local dairy and a manor house within a radius of some three kilometres. The numbers represent distances to the power station in metres. Source: Bjerre 1909.

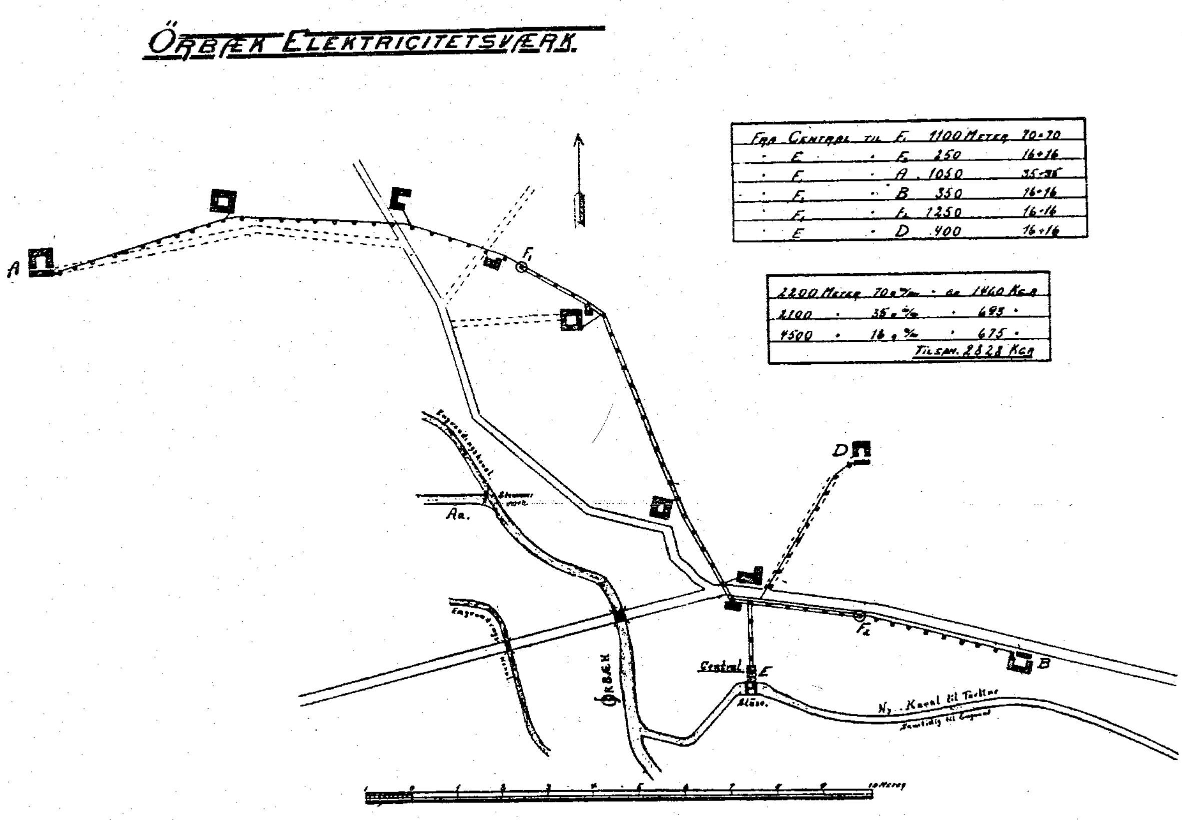


Figure 3.6: The local village supply system in Ørbæk, established 1911. The system includes only ten consumers, a small hydro power plant and few low voltage distribution lines. The largest distance from power station [E] to consumer [A] is 2350 metres. Source: Bjerre 1911.

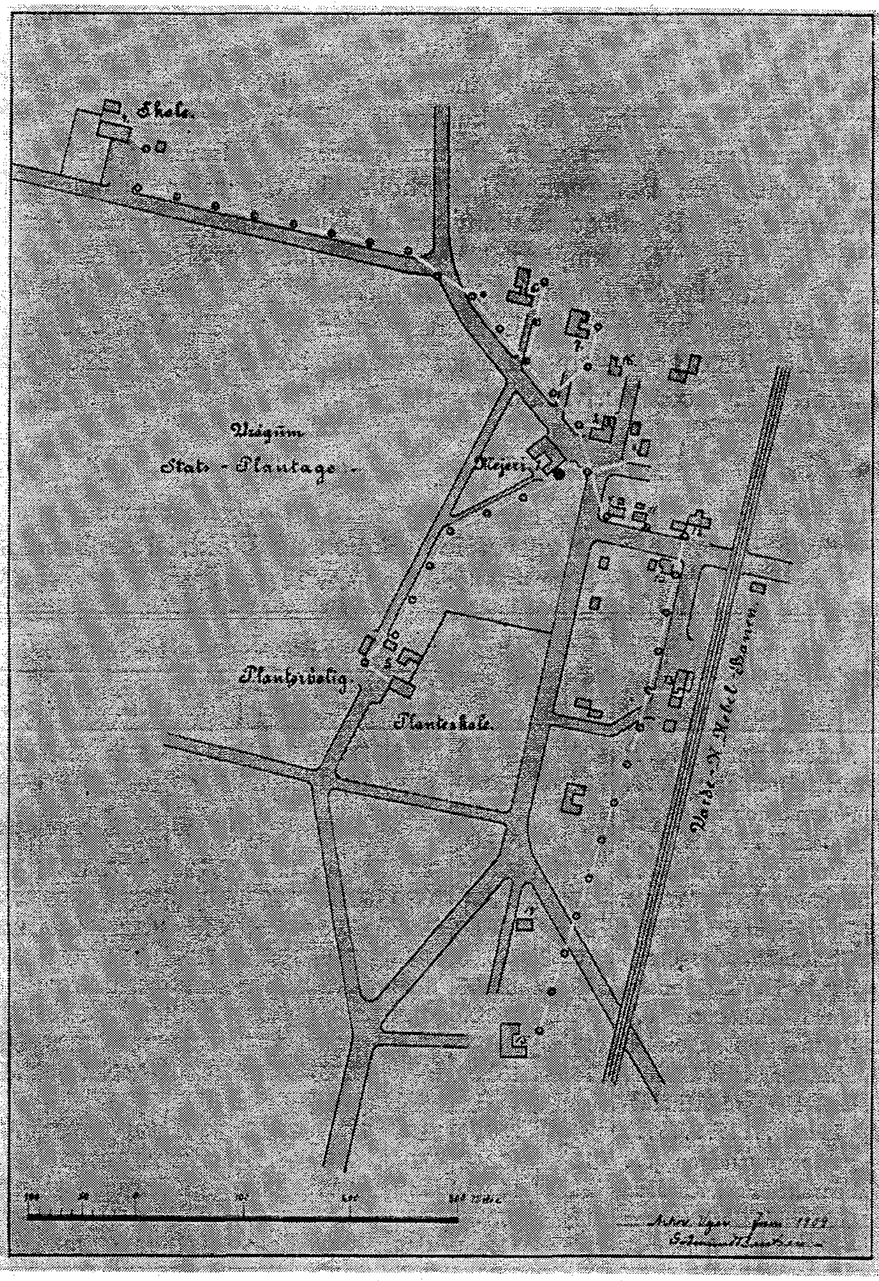


Figure 3.7: The local village system of Vrøgum in Western Jutland. The power station was combined with the local butter factory ['Mejeri'], and supplied sixteen consumers. Source: Bentsen 1909.

energy sources. With regard to utilities in larger towns of five to twenty thousand inhabitants, the average annual returns were more than ten percent. Just before the diffusion process of local supply in Denmark accelerated, then, municipalities were told that public electricity supply indeed could be a lucrative affair.

The diffusion of municipal local systems

Initiative

It is hardly surprising, then, that the motive of economic returns of electricity supply also turned up in the decision processes within the single municipalities. This is not to say that the issue of municipal electricity supply was placed on the agenda by discussions on profits in municipal journals; as described above, it was often a private application for a concession that started the debate in the municipal council. It might also be a request by local consumers - often large consumers as the Danish State Railways - for electricity.[54] And particularly from around 1905, engineering firms might bring up the issue to the municipalities, presenting complete technical supply schemes and promises of profitability. The consulting engineering firm of Peder Anders Pedersen, established in 1906, deserves particular mention. Employed at the Copenhagen utility, Pedersen was drawn into the consultancy business when he was engaged for consultance on a public electricity supply system in the town of Randers. Thereafter he founded his own firm, and used the Randers scheme as a model and a reference when approaching other municipal councils with proposals for local electricity supply systems. His activities coincided with the boom of municipal utilities in provincial towns, and his firm would be the principal technical consultant of municipal utilities during the period under consideration in this study: It would design some twenty-eight town systems in the following twelve years, that is, forty percent of the local systems established in market towns in that period. In addition, it was engaged as a consultant by a number of others.[55]

Economic municipal concerns in Randers and Nykøbing

In all circumstances, it was the municipal council that had the power of decision, while it as a rule delegated the investigation of the matter of electricity supply to a committee of council members, often the existing gas lighting committee. The main concerns in municipal discussions on its engagement in electricity supply were those of providing a public service and of economic profitability of the business. Illustrative are the decision processes in the municipalities of Randers in Jutland and Nykøbing on Falster, which established local electricity supply systems in the beginning of the municipal utility boom around 1906. Moreover, both were subsequently visited by municipal committees from other towns, and thus functioned as examples in the diffusion process.

In Randers, one of the larger Mid-Jutland towns with some twenty-three thousand inhabitants by 1910, the municipality did not own the local gaswork, and hence was not concerned for possibly decreasing gas sales. When the municipality decided to engage in the electricity supply business, profitability was a decisive motive. It was already briefly mentioned above that the municipality took up the issue of electricity supply after a private concession application in 1904. To investigate the matter in detail, the municipal council appointed a committee, which in turn hired consulting engineers to design a local supply system and calculate its economical feasibility. Indeed, consultant Peder Pedersen and his partner did promise an economic advantage for the municipal treasury: While the utility would yield a deficit for the first and perhaps the second year of operation, it would thereafter yield increasing annual profits (table 3.2). The committee then recommended the municipal council to establish a municipal utility, arguing on one hand that the municipality should keep up with modern developments, and on the other hand that electricity supply could be regarded a major active, which after the first years would yield increasing profits. This advantage outweighed the inconvenience of increasing the municipal debt with a loan of some four hundred thousand DKK (the final costs would be some 750.000 DKK). The municipal council unanimously decided to follow this recommendation, and the supply system became operational in 1906.[56]

Table 3.2: Expected and factual annual balance of the Randers municipal utility. The expected balance was worked out by the consulting engineers, and formed the basis for the decision of the municipal council to establish a municipal utility. Source: Westergaard 1931, 12 and 16.

	1st year	2nd year	3th year	4th year	5th year
Expected annual costs	28.275	30.270	32.635	34.695	36.015
Expected annual income	14.890	23.530	33.530	41.100	47.670
Expected surplus	-13.385	-6.740	895	6.405	11.655
Factual surplus	9.156	12.465	18.734	18.523	27.905

In practice, the economic returns turned out even higher than expected. While the satisfaction of the consumers was expressed by a fourfolding of the electricity demand after merely three years of operation, the plant manager gladly reported that the electricity sales outweighed the running costs from the very first year of operation, even though the utility had expected losses in the first two years. As annual interests and repayments were due only from the fourth year of operation, the utility in fact always run with a profit.[57] In 1910-11, the sixth year of operation, the utility yielded a net profit of forty-one thousand DKK.[58]

Contrary to the Randers municipality, the municipality of Nykøbing - a market town of some eleven thousand inhabitants in 1910 - on the island of Falster did run a local gas works.[59] This nicely illustrates the importance of economic considerations in the decision to establish a municipal electricity supply system, which would be operational in 1907. As described in a revious section, the issue was finally placed upon the municipal agenda as the result of a lobby by local industrialists, among which the local steam miller who had operated his own block station for about a decade. But in taking the issue seriously, the municipality had to overcome its fears of decreasing gas sales. Earlier, the gas lighting committee of the municipal council had responded very reluctantly towards private applications for the establishing of local electricity supply from the mid 1890s. Its negative verdict led the municipal council to reject the 1895 application by the steam miller, and although two years later it accepted an application by a hardware man against the votes of the members of the gaswork committee, the latter managed to obstruct the project by negotiating rather harsh concession conditions (including an obligation to run the electric power station on gaswork gas and to refrain from electric street lighting). The applicants subsequently withdrew. Although the issue had been treated in municipal journals, it was only in 1906 that the gas lighting committee gave up its opposition, following concrete experiences from other Danish municipalities proving the fear for decreasing gas sales wrong.

In this situation, again the promise of economic feasibility of the system provided a decisive argument for the municipal decision to establish and run its own system. This element was thoroughly investigated. Firstly, the consulting engineer of the municipality (again Peder Anders Pedersen) predicted that the system could be run with an annual surplus. In addition, the municipality sent an investigating committee to visit existing municipal systems in for instance Randers, Kolding and Copenhagen, where they received very positive comments on municipal electricity supply as well as the competence of their consulting engineer. Finally, it was argued that the local block station run by the steam miller had a significant annual profit of more than eight thousand DKK, and that its consumers could be expected to shift to municipal supply.

Finally, this economic concern of the municipality is reflected in the municipal decision to extend the distribution network only to areas, where consumers had been contracted for sufficiently many installations to secure a return on investment. Due to the rapidly increasing interest of the citizens in electricity, however, in few years the system was expanded to cover most of the inner city (figure 3.3). By 1910-11, the system indeed gave a net profit of some twenty-eight thousand DKK.[60]

Economic arguments in the municipal decision process

The available evidence suggests that the expectation of a profit for the municipal treasury often was a lead motive for municipal engagement in the electricity supply business, as it was in the cases of Randers and Nykøbing.[61] Often, municipalities verified promises of profitability of consulting engineers or the municipal press by visiting municipal utilities already established. In the case of Horsens (some twenty-four thousand inhabitants in 1910), for instance, a municipal council committee recommended the council to establish a municipal utility with reference to the fact that experiences from other municipalities suggested that 'electricity supply systems not only provide a return on investment, but even yield a profit, while gas sales do not decrease.' This supported the assessment of the expected income and costs, promising an increasing economic surplus after the first year of operation.[62]

Moreover, the economic success of these and other utilities established around 1906 were a direct stimulation other municipalities to follow the example and thus for the following acceleration of the diffusion process of local systems. For instance, while the municipal system of Nykøbing Falster had been inspired by those in Randers, Kolding and Copenhagen, it was in turn visited by others. Among these was a committee of the municipal council in Silkeborg in Jutland (some nine thousand inhabitants), which sought to verify the effects of electricity supply on gas sales in 1910. In this way, the Nykøbing system was drawn into the decision to establish a municipally owned local system in Silkeborg, operational in 1911.[63]

Also in the cases of municipal take-over of privately run town systems, the arguments of public service went hand in hand with that of improving municipal economy. In Slagelse, where a limited company had operated a local system since 1893, a municipal council commitee recommended the council to take over the supply business as specified in the concession terms. One argument was that the private system did not function satisfactorily; another that the municipality was in need of new sources of income. In Vejle, where a limited company had operated a local system since 1895, there was likewise dissatisfaction with the private operation - the utility was not able to supply all customers, and its high prices gave local handicraft a competitive disadvantage to their colleagues in other towns. But the municipality was also dissatisfied with the income it obtained from the private utility, which in the concession was set at an annual fee of eight hundred DKK. This was less than its electricity bill for buying electric street lighting. The municipal take-over of the electricity supply business was thus also economically motivated. And in Frederikshavn, where a limited company had operated a local system since 1900, the issue of municipal take-over was brought on the municipal agenda in 1906 with the motive that the private utility had a substantial net profit, which probably could be increased in municipal operation.[64]

By the end of the First World War, the municipal engagement in electricity supply had become a significant factor in municipal economy. This may be illustrated by its relative importance in the accumulated budgets of Denmark's about eighty market towns, most of which had a municipal utility running either a local or a district system.[65] Taken together, the budgets balanced with some fifty-six million DKK. On the income side, taxes (mainly income taxes) made up more than 83% of the total income, while direct support from the state (excluding additional loans) was marginal with less than 1%. The remaining income stemmed from capital and business income, in which profits from public electricity supply (6%) was the largest single post, followed by returns on capital investments and real estate (5%), gas supply (3%) and water supply (1%). With regard to expenses, the largest single posts included social service (43%), education (14%) and health care (7%).[66]

Electricity supply had thus been integrated in the municipal economy; and as a survey of the mid 1930s shows, municipal electric utilities mostly took profits of twenty to thirty percent of the electricity prices.[67] Only rarely municipalities refrained from taking such profits. For instance, in Kerteminde on Funen the municipality was particularly sensitive for the wishes of local citizens and directly involved them in the decision process through a referendum in 1910. Although the majority voted for the municipality to take up electricity supply, even here the municipality soon regarded the profits as an active to the municipal treasury, instead of a possibility to lower the electricity prices for the benefit of the consumers. In fact, the town of Odder in East Jutland provided a lonely exception of pure concern for the consumers: Only here, the municipality agreed in dialogue with future consumers that the goal of public electricity supply was to provide electricity to the consumers as cheaply as possible. A potential profit of the supply business should thus be used to reduce electricity prices rather than to improve the municipal budget. Notably, this deviating motive resulted in an alternative ownership form: The Odder electric utility was not founded as a municipal utility, but as a self-governing institution, which was run jointly by municipal and consumer representatives.[68]

The establishment procedure

Once the municipal council had decided to establish a municipal electricity supply system, its lighting committee would carry out the practical details. With regard to the physical construction of the local system, consulting engineers were engaged for the design, and different suppliers were invited to offers equipment. In the end, however, the equipment of local town systems - particularly those with Peder Pedersen as their consulting engineer - was often the same, and consisted of a diesel engine from the Danish machine works Burmeister & Wain, a dynamo by the Danish electrotechnical manufacturer Titan, an accumulator from the German manufacturer Gottfried Hagen (Köln) and a distribution network installed by the Danish branch of the recently merged German manufacturers Siemens and Schuckert.[69] To finance the investment, the municipalities had plenty of security and therefore obtained cheap loans.

An example is the local system established in Svendborg on Funen in 1906, a market town with som thirteen thousand inhabitants (1915), see figure 3.4. Of the total investment costs of more than three hundred thousand DKK, the largest single posts were the Siemens Schuckert distribution network including electricity meters (43%), the B&W diesel engines with directly connected Titan dynamos (24%), the building (18%) and the Hagen battery (6%). The distribution network and the dynamo were supplied through the Danish machine factory S. Frichs Efterfølgere in Århus. Contrary to the Nykøbing Falster system above, it used the three wire system with an effective distribution voltage of 440 volts, and could therefore economically supply consumers up to some three kilometres from the power station by 1910. Notably, also the Svendborg municipality had engaged Peder Pedersen's firm as its consultant, and also here the economic results surpassed the expectations.[70]

With regard to the organisation, finally, the electricity committee of the municipal council would assume the task of surveying the utility. It would also negotiate on behalf of the utility with other actors and investigate larger decisions, which had to be taken in the municipal council. For daily operation of the utility it engaged a plant manager. In Svendborg, a plant manager was engaged during the construction process, while in the first year or operation a second machine operator and an assistant were added. With the growth of the utility, it gained separate departments of administration, machinery and distribution. By 1930, these departments had some twenty employees.[71]

Producing a context for rural electrification

As we saw before, the majority of Danish local electricity supply systems was established and exploited by consumer associations in rural Denmark. In retrospect, this form of organisaton including collective ownership, management and liability is not surprising. For by the turn of the century, rural inhabitants had embraced co-operative ownership of production facilities in a similar way as municipalities had embraced the principle of municipal socialism. It was already described in the previous chapter, how the co-operative organisation of butter factories had proven very successful in the 1880s and 1890s, resulting in a rapid growth of the dairy sector, which in turn contributed to a flourishing of Danish rural economy. Moreover, in the following decades rural Danes developed the co-operative idea into a movement with regional and national interest groups, service (wholetrade, banking) organisations and co-operative factories, including a machine factory and also the co-operative cement factory mentioned in chapter two. By the First World War, the typical Danish farmer was a member of a number of co-operative societies, and Danish agricultural society had developed its characteristic high degree of organisation.[72]

Electricity in agricultural organisations and press

When electricity was placed on the agenda of rural Denmark, then, consumer ownership was both practically known and ideologically popular. But for this actor group of rural consumers to massively engage in the electricity supply business, the issue had to be concretely placed on the agenda as a rural concern. Until the beginning of the twentieth century, however, representatives of Danish agricultural interests found the prospects of electricity in agriculture low, although it had been given some attention. Already in 1894 the Royal Society of Agriculture had appointed a committee to investigate the importance and conditions of electric lighting in agriculture. The committee published its report the same year, but did not agitate for the introduction of public electricity supply in rural Denmark. Instead, it described the basic technologies involved and studied the costs of actual autoproduction systems for farms.[73] It found these costs rather high, and although it acknowledged the qualitative advantages of electric lighting and particularly their reduced danger of fire (which would result in a decrease of the fire assurance fees), it doubted that such rural autoproduction systems could be economically feasible.

Electricity remained a rarity in Danish agriculture, both in practice and in the agricultural press.[74] Rare cases of attention to the new technology included the inventive activity of Poul la Cour in the early 1890s (see below), agricultural protests against plans to establish electric traction in Copenhagen (thereby 'threatening' the agricultural production of horses and oats), and notice of some German innovations of electrified agriculture concerning for instance electric ploughing.[75] Electricity was generally found too expensive. This may be illustrated by the enthusiastic notice of the Frenchman Riché's invention of a gas engine running on gassified wood refuse, which had been presented driving a dynamo in an exhibition in Paris in 1900: It was noted that in Denmark, in want of hydropower, electricity was too expensive for agriculture; but the new gas system might enable the farmer to introduce electric light and power.[76]

Invited by the Royal Society of Agriculture to talk about the status of electricity in agriculture in 1901, the state-employed agricultural consultant C. V. Birk still found its economic prospects unambiguously dark.[77] Still implicitly thinking of autoproduction systems for the single farm, Birk stressed the high investment costs of electricity supply systems as the main obstacle for the electrification of agriculture: An electric power system cost about three times as much as a steam engine, thus making interest and repayment a major hurdle in the annual expenses of such a system. The relative importance of these sunk costs could in principle be reduced by increasing the usage time of the system, so that the sunk costs became lower per unit of output. Yet for this, agricultural power demand was badly suited, as it was comparatively small and particularly unsteady. The largest power demand stemmed from field work, that is, ploughing. Other activities as threshing, grinding, chaff cutting and beet rasping demanded relatively little power for relatively brief periods of time. According to Birk, the economic feasibility of electric drive in agriculture therefore depended upon the economic feasibility of electric ploughing. But while German investigations found electric ploughing feasible compared to steam ploughing with a demand higher than thirty to forty horsepowers, Birk stressed that the German conditions differed from the Danish ones: In Germany ploughing technology was designed for deep ploughing, demanding a large power consumption and thus favourable to mechanisation with steam or electric ploughs. Danish farmers, however, generally used more superficial ploughs with lower power requirements, and which were normally pulled by horses. An economically feasible mechanization of ploughing in Denmark would presuppose a larger power demand for instance achieved by means of a wider plough, but such technology was not available. Electricity remained unattractive for Danish agriculture, then, unless special circumstances (such as a combination of agricultural and industrial purposes) tipped the scales to the advantage of electric drive.

When the issue of electricity supply was put on the agenda in national agricultural organisations again in 1905, however, the tide had begun to turn. In an address at the annual meeting of agricultural consultants, professor Poul la Cour of the folk high school in Askov in Jutland argued that electric power, although more expensive than power from steam or petrol engines, might well be economically feasible for many Danish farms, as it was cheaper than the most common power sources of human or horse power.[78] This was particularly true if the single farmer did not have to run a small power plant himself, but could buy his power from a public electricity supply system. According to la Cour, even a small public electricity supply system at the level of a village could yield a surplus of twelve to fourteen percent of the investment costs, thereby being able to return interest and repayment on the investment. To support his claimes, he could refer to the village electricity supply system in Askov he had established recently, and which was operated with economical satisfaction both for the utility and its agricultural consumers.

La Cour and the local village system of Askov

It was la Cour, then, who firmly placed the issue of electrification on the rural agenda by developing a feasible village supply scheme and actively promoting its diffusion in rural Denmark. Notably, while the agricultural consultant Birk had considered unsteady wind power as unsuitable for electricity production and petrol engines as competitors rather than supporters of electricity, la Cour's first local village supply scheme included exactly these two power sources: Wind electricity was the primary power source, while a petrol engine served as back-up.

In several ways, la Cour's effort for rural electrification - by his biographer H. C. Hansen (1985) called a second stage in his work starting just after the turn of the century - drew upon his work with windmill technology in the 1890s.[79] On one hand, this included technological results achieved at his test site for windmill technology, established on government support near his folk high school in the early 1890s. The purpose of this test site was to show that modern technology could make Denmark's omnipresent but unsteady natural resource, wind, into a cheap and regulable source of energy. Perhaps most important in retrospect was his invention of a device to create a steady power flow out of an irregular wind, which is a precondition for driving a dynamo. While the rotation of the wings of a windmill could vary with one hundred percent within a few seconds, la Cour's so-called 'cratostate' of 1892 produced a rotation with a variation below one promille. This achievement made la Cour known as 'Denmark's Edison' in the popular press. The context of this invention, however, was not a vision of electricity supply. Instead, the idea was to store wind energy: The electricity produced by a wind powered dynamo was used to electrolyse water and produce oxygen and hydrogen, which could be burned when necessary to produce power, heat or lighting. In practice, this vision was only partly realized; by the mid 1890s a system of hydrogen lighting was operational at la Cour's school, while joint attempts with a Danish machine works to develop a hydrogen engine failed.

And on the other hand, la Cour developed an increasingly explicit social concern for the welfare of rural Denmark, with its particular problems of mass migration from countryside to towns. Whereas steam power had previously concentrated people in large factories and cities, la Cour motivated his work with wind power technology with his concern to develop a small scale source of energy to stimulate rural industry and thus to counter the urbanization process. This concern obviously echos through late 19th century German industrial decentralization theory and bears particular resemblance to the work of Rudolf Diesel, who motivated as well as promoted his diesel engine with reference to its potential to support decentralisation of the craft industry, serving political, economic and hygienic purposes.[80] In Denmark, la Cour's concern for rural life was for instance expressed in that the cratostate was put freely at the disposal of Danish wind millers. Moreover, during the second half of the 1890s he engaged in aerodynamic investigations as well as investigations on the possibility to use wind electricity in a number of electrochemical processes, thus seeking to support the established sector of rural millers and to help establishing a new small-scale, wind-powered chemical industry on the countryside.

Requested to consult on the establishment of electricity supply systems in butter factories, and threatened by a reduction of his government grant just after the turn of the century, la Cour reformulated the cause of his test site into a support of the use of electricity in agriculture.[81] As a first part of this effort, the test mill was transformed into an exemplary power station, which should supply electricity to the village of Askov where it was situated. La Cour invited potential consumers to sign in for a certain lighting demand, promising to supply electricity at prices corresponding to those in Copenhagen at the time. The electrical equipment was ordered from the German firm Allgemeine Elektricität Gesellschaft, and the local electricity supply system in Askov became operational in 1902. Technically, the power station consisted of the wind mill driving a small small (six kilowatts) generator, supplemented by an accumulator, which should be able to continue supply for two days without wind. For supply in longer windstill periods, it also contained a back-up unit consisting of a petrol engine and a second generator. For supply of the village situated half a kilometer from the wind mill with one hundred volts, direct current electricity, la Cour chose a three-wire distribution network. By april 1903 the system supplied some 450 incandescent lights, few arc lights and few electromotors.[82]

The rhetoric of local village supply systems

With regard to the promotion of such local village supply systems, la Cour developed a rhetorical repertoire in his publications and his talks at agricultural, industrial and technical organisations. On one hand, he sought to convince the rural population with arguments for electrifying agriculture and for using local village systems achieve this. And on the other hand, he tried to convince 'outsiders' of the feasibility and importance of rural electrification with local systems with reference to the particular situation and demands of rural Denmark.

Like in the case of his earlier work, la Cour justified his cause of rural electrification as a central social concern to counter mass migration from the countryside to the towns. In an address to an industry society (1906), for instance, he maintained that electricity carried the possibility of a 'new industrial-social era'; whereas in the nineteenth century era of steam power the population had been concentrated around factory centres, increasing the size of large towns, and resulting in crises with overproduction and unemployment in towns and shortage of labour on the countryside, rural electrification could potentially reverse this movement by making a small and cheap power source available in the form of electric motors. Hereby small industries, handicrafts and farmers could mechanize their trade, improve rural economy and make it competitive to large scale industry in towns. For la Cour, this implied a 'more happy condition in both industrial and social aspects'.[83] La Cour maintained this vision even though critical contemporaries doubted this social mechanism, for instance suggesting that rural mechanisation might produce rural unemployment and thereby reinforce the urbanization process.

Besides the 'comfort and usefulness' of electric light, not in the least in barns and stables, la Cour focused in particular on the advantages of electric drive for rural Denmark.[84] With regard to agriculture, la Cour argued that electric drive in the field - as practiced already by some German manors - would probably be uneconomical. Contrary to agricultural consultant Birk, he found that electric power should be employed at the farm itself: Tasks like threshing, chaff cutting, oil cake crushing, beet grating and pumping could be performed much more conveniently with electromotors than with the power sources otherwise available in agriculture. Moreover, if electricity was provided from a common power station, the farm installations would be limited to hardly visible electric wires with lamps and few electromotors occupying only little space. One stationary electromotor could drive the threshing machine, while a second transportable one could perform various other tasks.

In addition, also rural handicraft, industry and domestic industry would benefit from electric drive. For handicraft and small rural industry, the advantage was a cheap power source which had no particular costs at the time of usage. And in domestic industry, electric drive might make the 'long winter nights' more productive, providing a supplement to the income from day labour. For instance, a weaver might six-fold his productivity by driving power looms with electric motors. Perhaps, la Cour suggested, the weaver could even make his trade a full time job and leave common day labour to others, thereby creating new rural employment.[85]

With regard to the supply of electricity, la Cour promoted his Askov supply system as most appropriate for the electrification of rural Denmark. He rejected the possibility of large scale supply from large power stations to large areas by means of high voltage transmission, known for instance from the system at Niagara Falls in the United States; such a supply system would be economically inappropriate to supply Denmark's dispersed rural population. The much cheaper option was to establish small common supply systems in places where several consumers lived close to each other, in villages, and to establish autoproduction systems at more isolated farms (see chapter six). His wind-electricity supply system was suitable for both.

To prove that a small-scale local electricity supply system in small villages could be 'technically and economically feasible', la Cour mobilized the results from the

Askov village system.[86] Supposing that the windmill had to be newly constructed and was not yet available as in Askov, the investment costs of a village system comparable to that of Askov would be as low as sixteen thousand DKK (table 3.3). By comparison, the smallest autoproduction system considered by Birk in 1902 (forty horsepower) would cost some twenty-eight thousand DKK (excl. installations and applications). Moreover, due to very low running costs, the system yielded an annual gross profit of nearly two thousand DKK, which corresponded to twelve percent of the investment and thus should be sufficient for paying interest and repayment. These low running costs were partly due to the rare use of the petrol engine; in the first period of the Askov system, there was sufficient wind to produce 92% of the energy. And partly they followed the low wages to a plant manager, as the windmill system thanks to la Cour's inventions worked automatically and only needed to be started and stopped. Running the petrol engine demanded more work and was thus more expensive.

Table 3.3: la Cour's presentation of the economy of a small rural village system in 1903, based upon the Askov system. Source: la Cour 1903, 100.

Investments:	(DKK)	**Annual running costs:**	(DKK)
Windmill:	3.000	Petrol:	200
Petrol back-up engine:	3.000	Wages windmill:	200
Accumulator:	5.000	Wages petrol engine	
Dynamo:	1.000	(running 30 days annually):	120
Additional equipment:	700	Lubricating oil:	80
Building and ground:	2.000	Total:	600
Distribution network:	1.300	**Annual income:**	
Total:	16.000	Sale: 5.000 kWh à 50 øre:	2.500
		Annual profit:	1.900
			(12% of the invested capital)

While la Cour initially focused upon wind electricity supply systems, focus later shifted to other sources of energy. In a 1907 publication, la Cour and his collaborator Jacob Bjerre maintained that different power sources were appropriate for different sizes of village systems. For instance, a system with 300-500 incandescent lamps and some smaller electromotors could be supplied by a six kilowatt power station, where primary power was provided by a wind mill with petrol engine backup. A system with 500-800 lamps and some electromotors might be supplied by a nine kilowatt power with a suction gas engine, while a system with 800-1500 lamps and some electromotors might be supplied with a seventeen kilowatt diesel generator.[87] Moreover, after la Cour's death in 1907 the establishment of wind power stations stagnated, and wind power rapidly lost importance to suction gas engines, which thereafter were rapidly replaced by diesel engines.[88] Only during the fuel crises following the two world wars, wind power was to gain larger importance in public electricity supply.

Finally, la Cour did not only address the rural population in an attempt to convince it of the feasibility of electrification. He also discussed his scheme with other social groups including urban electrotechnical experts, which were generally sceptical of rural electrification through small local systems. It was in this context, that he on behalf of the rural population formulated the specific rural concerns regarding electrification. First, contrary to town systems, rural village systems did not have to be a profitable business; the idea of rural electrification was not to derive a profit, but to electrify agriculture, and in this respect "even if these were small electric power stations, these were a big concern for the countryside."[89] Second, rural inhabitants would accept significantly higher electricity prices than city dwellers, simply because their energy traditionally was more expensive. Although rural electricity might be more expensive than urban large steam engines (one-two øre per horsepower-hour) and smaller petrol engines (seven øre per horsepower-hour), farmers compared the power costs of electric drive with those of a horse-mill. Therefore, electric drive (forty øre per horsepower-hour) had to be compared with horse mills (seventy øre per horsepower-hour) or human power (250 øre per horsepower-hour) and would thus be feasible. To this should be added qualitative advantages: In threshing, for instance, electric drive not only provided a more even process, but the flexibility of electric power transmission also made it possible to install the threshing machine in the silo where the straw was kept instead of close to the engine house or horse mill. This saved the labour of one or two workers for transporting the straw from the silo to the power house. Moreover, coming home from the field with tired horses farmers would hesitate to let them run a horse mill, but could easily start an electric motor.

A third concern followed the position of Danish agriculture in the international competition. Thus, even though the future option of supply from a large (town) power station through high voltage transmission might be economically attractive, farmers could not wait: On the international market, the concern was to be 'one horse head' ahead of international developments, in casu electrification, rather than a decade behind if the solution preferred by technical expertise was to be followed. In analogy, he reminded of the revolution in dairy production some decades ago: Here Danish farmers had not waited for polytechnical expertise to innovate, but taken initiative themselves to introduce mechanized cream separation, maximum cleanness, chemical control and souring in co-operative factories, thereby achieving their internationally dominating position. With regard to electricity supply, then, the less advanced technology of small local village systems was a cheap and easy technology, which could be established and operated by local communities.

The D.V.E.S. company

Some skills, however, were needed, and in this respect la Cour took the initiative for and co-founded the Danish Company of Wind Electricity [*Dansk Vind Elektrisitet Selskab*, D.V.E.S] in 1903.[90] The original idea with the company was to support rural electrification in case the government grant to la Cour would cease. As supporting measures, the company embarked on three fields; besides propagating the new technology, for instance through its own journal, it would provide consultance on rural electricity systems for a small fee, as well as organize courses to educate involved users and managers. As a consulting engineering firm, the D.V.E.S. company had designed some seventy local village systems by 1912, while its consultants had also visited a number of other systems.[91] Together with the agitation efforts to interest rural Denmark for electricity, this made the D.V.E.S. company an important actor in the early diffusion of village systems, on a par with the P. A. Pedersen firm in the diffusion of municipal town systems.

With regard to the organization of courses on electrotechnology, la Cour had already organized short courses (a week's length) for future managers to operate and maintain the electricity supply systems since the autumn of 1901. This task was taken over by the D.V.E.S. company, which also embarked upon the education of so-called rural electricians, thus producing an alternative to more expensive electricians coming out from larger towns. These courses included some three-months of theory and a final project, for instance the design and construction of a concrete village system. These courses ran from 1904 to the end of the First World War, in which period some two hundred and thirty rural electricians were educated.

The diffusion of local village systems

As table 3.1 illustrated, the diffusion of local village systems occurred rather swiftly. When the Askov system was established, village systems were still rare. There existed a system based upon a grain water mill in the Vejle county, where the miller sought to soften the crisis in his trade by providing his neighbours with electricity from the late 1890s. Two other systems established at the turn of the century were situated South of the German-Danish border until the latter was altered in 1920.[92] In addition, there were local systems in some very small towns such as Haslev and Faxe (2500 and 1100 inhabitants 1901 respectively) on Zealand.[93] Yet by late 1905 there were sixteen village systems, by 1910 nearly one hundred-eighty and by 1915 more than three hundred.

The initiators of consumer owned utilities

A sample of the establishment processes of rural local systems suggests that sometimes the initiative stemmed from farmers, but certainly also quite often from local handicraft, industry or shopkeepers.[94] The motive to establish electricity supply systems in small rural communities was thus just as much to electrify these latter trades as to introduce electricity in agriculture. This may be illustrated by the representation of these different groups in preparatory committees and the first executive boards of rural utilities. Agricultural interests for instance dominated the establishment of the local system supplying the villages Hasmark and Egense on Funen, run by an executive board consisting of five local farmers. And in Kappel on the Western edge of Lolland, the utility board included two farmers, a manor and the local parish official besides a local director. Finally, the initiative for the erection of the 'Thor' utility in Hjerm in Western Jutland was taken by a farmer, who brought up the issue in the local control association (a local farmer association surveying and improving milk production); moreover, the first executive board consisted of five farmers besides a shopkeeper and a baker. All three local systems were organized as co-operative societies and became operational just before the First World War. They supplied areas of a varying size: The supply area of the Kappel system included six hundred inhabitants, while the Thor system covered an area with some three thousand inhabitants (1921).[95]

On the other hand, local handicraft of business interest dominated the establishment of local systems particularly in larger villages or small towns, as the involvement of representatives for a varied village business life illustrates. In Hals in Northern Jutland, for instance, the committee preparing the establishment of a local system consisted of a carpenter, a shoemaker, a timber merchant, three shopkeepers and a baker. In Arden, likewise in Northern Jutland, the preparation committee included the manager of the local sawmill, a tailor, a local entrepreneur, a shopkeeper and a doctor. And in Ølgod in Western Jutland, the initiative for the system was taken by a timber merchant, two shopkeepers, a hotel owner and a smith. In other cases, local trade and handicraft associations even formed the organisational setting for the preparatory work; in Tørring in the county of Århus, for instance, a saddler brought up the issue of electricity supply at the annual meeting of the local handicraft association, while in Ulfborg i Western Jutland a local veterinary surgeon brought up this issue at the 'local association of citizens and handicraft'. These associations then delegated the preparatory work to commitees representing local business life. All these systems were established between 1906 and 1913, and like the farmer run systems mentioned above were organized as co-operative societies. They supplied areas with 1000 to 1300 inhabitants (1921).[96]

No matter whether the establishment of local village systems was carried through by representatives of agriculture or of village trade, handicraft or industry, the organisational pattern was often the same.[97] An influential individual or possibly an installation firm would raise the issue in the local community, and the local inhabitants were invited to a meeting at the village hall for further discussion. The initators might also invite experts, like la Cour and Jacob Bjerre from the D.V.E.S. company or other consulting engineers, to explain the options and the feasibility of electricity supply. Such meetings might then appoint a committee to furter investigate the establishment of a local electricity supply system. Moreover, the future electricity demand was estimated on the basis of lists, on which consumers could sign in for a number of lamps or a particular power demand. The committee would then hire electrotechnical expertise for designing a supply scheme and calculating its feasibility, and investigate the conditions of loans. The results would be presented to the assembly, and if the prospects were good, the committee might call for a founding meeting of a joint electricity supply undertaking, mostly in the form of a co-operative society. Then an executive committee would circulate binding subscription lists and invite concrete offers on equipment, whereafter the general assembly decided on the continuation of the project.

The character of the co-operatively owned village utility is reflected in its typical statutes, which remind of those of the co-operative dairies. The statutes accepted by the general assembly of the co-operative local system of Tørring may illustrate some of the principles.[98] To start with, the goal of the utility was to provide electric light and power as cheaply as possible for members of the co-operative society as well as for non menbers. Second, a building committee was authorized to negotiate with money institutes on a loan, for which the members would be collectively liable. Third, the consumers - members or non members - were obliged to annually pay for the minimum use of lighting for which they had signed in, for a period of ten years. Fourth, electricity prices were set annually at the general assembly. Fifth, an executive committee was authorized to supervice daily operation and engage a plant manager and possibly other personel. And sixth, the general assembly would have the decisive power on any major issues. Decisions would normally be taken with a simple majority of votes, while a change of the statutes or the dissolution of the society demanded a larger majority.

Cases: Consumer owned local supply for small and large villages

Such actors, then, regarded local village systems as the suitable form of electricity supply in large and small villages. An example of a relatively large system is the system in Skamby on Funen. The matter of electricity supply was discussed at the village hall in 1907, where engineer Bjerre of the D.V.E.S. company gave one of his talks. A committee chaired by a local farmer investigated the possibility of supply from a high voltage system for instance from Odense, but finally decided to build a local system, owned by a co-operative society. This system would supply both the main village of Skamby and the village around the nearby train station, as well as two small nearby villages of Bare Brøndstrup and Ullerup. However, in a final stage five more small villages and a manor were connected, making the Skamby system 'the largest village electricity supply system in Denmark', as it was put in 1909 (figure 3.5). In its supply area lived some nine hundred inhabitants (1920), and the system supplied one hundred consumers with more than twenty-four hundred lamps and sixty electromotors. On the supply side, power was produced by two suction gas engines, a larger dynamo (eighty kilowatts), two smaller ones and a battery. A 440 volt distribution system facilitated a relatively large supply area with a radius of some three kilometres. The supply system, designed by the D.V.E.S. company and constructed by Siliam Bjerre, Skive, cost ninety-six thousand DKK, while installations and applications cost eighty-four thousand DKK. The equipment was purchased from Danish factories apart from the battery and the electricity meters. All expenses were covered by a common loan, to be repaid only over twenty five (supply system) or ten years (installations).[99]

The technology of local village supply, however, was also deemed appropriate for very isolated villages. The co-operatively owned system established by the D.V.E.S. in the village of Ørbæk (200 inhabitants in 1920) in Western Jutland, for instance, was described as an 'electrification of one of the country's most isolated areas.'[100] Operational in 1910, the system included only ten consumers: seven farms, a single smallholder, a local dairy and a local co-operative store. The electricity case was carried through on the initiative of a local farmer. The supply system cost only a fifth of the Skamby system above, some eighteen thousand DKK, part of which was used for a hydropower installation (a canal, turbines chamber and turbine). Installation costs at the consumers were only six percent of those in Skamby (five thousand DKK) for two hundred incandescent lamps and nine electromotors accumulating thirty-four horsepowers. The system capacity was only seven kilowatts, and the distribution network reached about two kilometres from the hydropower station (figure 3.6).

A final example is that the local village system of Vrøgum, also a very small village (200 inhabitants in 1920) at the coast of Western Jutland, but less isolated as it did have a railway station. The system waa also built by the D.V.E.S. company, and the utility was established as a co-operative society, but in close cooperation with the local co-operative butter factory. The butter factory supplied the primary energy: It invested in a larger boiler and steam engine of some ten kilowatts, four kilowatt of which were used to draw the dairy machines, while the rest was available to the electric utility. The butter factory also provided room for the power station - a dynamo, battery and control board. The distribution system consisted of a two wire system of 220 volts, and supplied merely sixteen consumers. Besides the butter factory, the light consumers included a local co-operative store, the parish school, a plantation, a shoemaker, a hotel, the railway station, a farmer, a painter, a carpenter and a sewer. Power was purchased by a fodder firm, two farmers and a builder. Exclusive of the power machinery, the electric supply system cost less than half (seven thousand DKK.) than that in Ørbæk, while the costs of lighting installations probably were comparable.[101] This in effect six kilowatt system, operational in 1908, included a 440 volt distribution network, although the largest distance between power station and consumer was merely six hundred meters (figure 3.7).

Rural economy and village systems

The explosive growth from 1906 of the number of rural local systems already indicates that this form of rural electrification could be economically feasible. Moreover, as in the case of the urban municipal utilities, successful examples must have stimulated the diffusion process. Among these were utilities, the (positive) results of which were published in the journal of the D.V.E.S company. One of these is the co-operative society exploiting the rural system in the small town of Hammerum (some 1300 inhabitants in 1920) in the Ringkøbing county in Western Jutland. Operational with a diesel power station from 1905, this utility supplied some fifty consumers at average electricity prices of forty-five øre per kilowatt-hour for light and twenty-two for power. With these prices its annual surplus was large enough to pay interest and repayment (table 3.4).

Table 3.4: Balance of the Hammerum electricity supply company 1906-1908. Source: Tidsskrift for Vindelektrisitet, 488-489.

	1906	**1907**	**1908**
Income:		(DKK)	
Light	3161	3494	3713
Power	746	1643	2462
Other	103	100	110
Total:	4010	5237	6285
Running expenses:			
Wages:	450	560	660
Diesel lubricting oil:	580	700	712
Taxes and insurance:	200	188	106
Other:	138	195	307
Total:	1368	1643	1785
Surplus available for interest and repayment:	2442	3594	1785
In % of investment sum:	9.1%	12.3%	14%

Although the first electricity supply statistics for 1910 are rather incomplete with regard to information on the economy of rural local systems, they suggests that the customary electricity prices of some forty-fifty øre per kilowatthour for lighting and twenty-thirty øre per kilowatthours for power - which compared to those of many middle-sized and smaller municipal utilities - were sufficient for most small rural utilities to balance their annual budgets. An example of a utility in a larger village is that of Dronninglund in Northern Jutland (some 800 inhabitants), which operated with electricity prices of 40/20 øre per kWh lighting/power in 1910-11. In that year, these prices resulted in a gross surplus of 9% of the invested capital, which in fact meant a net profit of some two thousand DKK. And an example of a utility in a smaller village is that of Viuf in the Vejle county in Eastern Jutland (some 200 inhabitants), which operated with similar electricity prices in 1910-11. This utility had a gross surplus of 6% of the invested capital, which was enough for a net balance of the budget.[102]

The other side of the question, then, is whether the consumers were satisfied with these or higher electricity prices. In this respect, it seems that la Cour's argument that on the countryside even relatively high electricity prices might be acceptable is qualified. An example is the very small local system in the village of Knardrup in Northern Zealand, established in 1906 by a co-operative society of merely seven consumers: Four farmers, a carpenter, a brewer and a baker, each having an electromotor of their own and merely one hundred eighty lamp connections in all. Primary power was supplied by the baker, who owned a Dutch windmill, and was engaged by the co-operative society to supply its small (8.5 kilowatts) dynamo and operate the system (including a back-up diesel engine) for a small annual fee. In return, the consumers obliged themselves not to grind corn at home. In 1907, the budget was balanced by a comparatively high electricity price of seventy-five øre per kilowatt-hour for light as well as for power.

Nevertheless, the consumers expressed satisfaction. One of the farmers, who used electricity for threshing, chaff cutting and lighting, was said to have saved seventeen percent on expenses compared to previous steam threshing and traditional lighting. To such economic savings could be added 'easiness, comfort and better exploitation of straw and chaff.' Also the brewery's expenses for power and lighting had been reduced, and it was concluded that a comparison between past and present would be to the advantage of electricity. As the baker put it, 'electricity in the service of agriculture is uniquely comfortable, reliable and - even at a high price - economical.'[103] In 1910-11, the utility still had about the highest electricity prices of all village utilities registered, charging 85/20 øre per kWh for lighting/power to balance the budget.[104]

In sum, two actor groups were primarily responsible for the rapid diffusion of local systems: In the majority of larger and middle-sized Danish towns, the municipalities established their own electric utility. Most of were these still running a local system by the early 1920s, although an increasing number had abandoned local supply for district supply. Politically a strong actor in Denmark, Danish municipalities interpreted electricity supply not only as a benefit for their towns, but also in the tradition of municipal trading as an active for the municipal treasury. This profitability of electric utilities was a primary focus in treatments of the issue in the municipal press, and often proved a decisive motive for individual municipalities to engage in the electricity supply business.

On the other hand, a large number of consumer associations established electric utilities in villages or very small towns (that is, towns with for instance between 1000-2000 inhabitants). Rural inhabitants did not consider electricity supply as a means to derive a profit, but as a means to electrify agriculture or rural handicraft and industry and thereby improve their competitiveness. Instead of waiting for electrification to come from larger utilities in towns, they often preferred to establish their own local systems in the form of the co-operative society, a form of organization independent of town actors that had already proved its worth in the dairy branch in the last decades of the 19th century. While such rural local systems clearly outnumbered urban local systems run by municipalities, the latter were in average much larger, and in terms of electricity output the importance of urban and rural local systems was about equal.[105]

4
District systems

Developments abroad

District supply systems, in this study demarcated from local systems by the use of high voltage electricity transmission for economical electricity transport, were not introduced in Denmark until 1907. Like local electricity supply before its introduction in Denmark, by then district electricity supply had been invented, developed, and to a high degree stabilized abroad.[1] Again the invention had been tied up with a vision of a scale increase in electricity supply: Already in the first half of the 1880s, the Frenchman Lucien Gaulard and his British partner John Gibbs had proposed a "system of distribution limited neither by the distance of the central factory from the point of consumption, nor by the number of consumers to be supplied."[2] To achieve this, they based their supply system on alternating current, where - contrary to a system based on direct current - the voltage level could be easily altered by means of transformers: In a district system, a so-called 'step-up transformer' at the power station would produce high voltage, alternating current. This was economically transported on a 'primary circuit' or transmission network to the different substations near the consumers. Here, so-called 'step-down transformers' produced low voltage, alternating current for transport to the consumers on a secondary circuit.[3]

In the second half of the 1880s alternating current supply was improved and taken into common use. By 1890, for instance, the leading electrical manufacturer Ganz & Company in Austria-Hungary had installed some ninety alternating current systems, while Westinghouse in the United States had installed some three hundred.[4] By then, direct current and alternating current technology competed heavily in what contemporaries perceived as 'the battle of systems'. As Hughes (1983) has demonstrated, this competition was resolved in the 1890s, not by replacing direct current technology with alternating current technology, but with the possible combination of both technologies in one larger scale supply system. This was technically achieved by means of so-called couplers, that is, installations to convert alternating current into direct current or vice versa. As direct current distribution systems could be coupled to alternating current transmission systems, Hughes sees the rise of the 'universal system': A larger scale type of system, extending its supply area both by increasing the transmission distance with high voltage transmission and by diversifying its consumer basis by locally providing any kind of current and voltage.[5] The term 'district system' in this dissertation signifies only the use of high voltage transmission, and thus includes both such combined systems and pure alternating current systems.

When the issue of district systems became relevant in Denmark, its advantages had been convincingly demonstrated abroad. The ability to transport electricity economically over larger distances did not only facilitate an increased supply area: It also made it possible to concentrate electricity production where it was cheapest. On one hand, thermal power production could be concentrated in large power stations exploiting economies of scale, situated outside the cities where the land was cheap and there was access to water for cooling and supply of coal by barge. The power station build on the bank of the Thames in Deptfort near London, supplying parts of London with a transmission voltage of 10 kV from around 1890, is a famous example.[6] On the other hand, cheap but distant hydropower resources could be made available to consumption centres. Famous events include the system built for the International Electrical Exhibition in Frankfurt on the Main in Germany in 1891, as well as the system build to exploit the huge hydropower resources at Niagara Falls in the United States, which became operational in 1895. The Frankfurt system demonstrated that long distance transmission of hydropower was technically possible; it involved a 178 kilometres long transmission line, which transported surplus power produced at the hydropower station of a cement works at Lauffen to the exhibition in Frankfurt. Using a transmission voltage of twenty-five kilovolts, the system had a transport capacity of some hundred and forty kilowatts, and surprisingly modest losses of less than thirty percent. The large scale Niagara system added to this an enormous appeal to human imagination by demonstrating how huge hydropower resources could be tamed and made productive, supplying cheap hydro-electrical energy partly by eleven kilovolts to the city of Buffalo, partly by two kilovolts to large factories built at the site.[7]

In the following decades, the front development of high voltage transmission technology closely followed the exploitation of distant hydropower resources, which pushed for instance the construction of power lines for still higher voltages. By 1914 there existed some fifty-five systems in some fifteen countries, which used transmission voltages of seventy kilovolts or more. Almost all of these transported hydroelectric energy to consumption centres, crossing distances up to three hundred and forty kilometres.[8]

The idea of high voltage transmission in Denmark

The peat argument

In Denmark, however, there are only few and modest hydropower resources. Nevertheless it was the hydropower motive that set off the discussion of district supply: It was adapted to Danish - particularly Eastern Danish - natural geography, where the only naturally available power source of importance was peat. With reference to the possible exploitation of 'huge peat energy resources', a supportive context for district supply was formed before it was actually introduced. This includes the establishment of an electrical engineering education at the Polytechnical School [*Polyteknisk Læreanstalt*] in Copenhagen in 1903, which focused particularly on alternating current engineering, as well as the first Danish Electricity Supply Act in 1907, which had been on its way from 1903 and aimed to make possible the establishment of transmission systems on land not owned by the power company.

The argument for peat energy was for instance presented with great force at the Nordic Technical and Hygienical Congress held in Copenhagen in 1903. While the section on electrotechnology addressed various other issues on power as well as signal engineering, the possibilities of high voltage transmission to make peat energy productive was addressed in the chemical section by Niels Steenberg, a professor in chemical engineering at the Polytechnical School, connected to several chemical industries and a leading figure in the establishment of an association for the peat bog industry in 1901.[9] Steenberg particularly pointed at the successful exploitation of hydropower resources abroad: The energy in large waterfalls had been 'squandered', until economic electric power transmission made it possible to transport it from the site to the point of consumption. Moreover, the electric energy was directly made productive in large scale chemical and metal industries, for instance in the production of aluminium and nitrogen fertilizer or electrical copper refining and cast iron production.[10]

According to Steenberg, the Danish peat bogs represented a similar energy source. Like hydropower, peat had to be exploited at the site, because its low energy value per volume unit made it uneconomical to transport compared to hardcoal. The energy value of peat could technically be improved, but this would be expensive and therefore still make its use uneconomical. And like hydropower resources before the introduction of electric power transmission, the peat bogs were hardly exploited at all. By means of high voltage electricity transmission, then, peat energy could economically be made available at the places of consumption such as towns, and in the near future possibly at agricultural centres.

Steenberg exemplified his idea with a concrete supply scheme, which should make available energy from the Aamose peat bog near Holbæk on Zealand to the consumers in Copenhagen some sixty kilometres away. In the power station at the peat bog, the peat would be gassified and burned in efficient gas engines driving electricity generators. A step-up transformer would then raise the voltage level to thirty kilovolts for transport to a substation in Copenhagen. Here a step-down transformer would lower the voltage level to five kilovolts for further transport to consumer junctions in the Copenhagen area, where other substations would produce low voltage, alternating current for consumption. According to Steenberg's calculations, this system could under optimal conditions (i.e. full exploitation) supply Copenhagen with electricity for under five øre pr. kilowatt-hour, including interest and repayment, maintenance, administration and fuel. Even though the real costs might be considerably higher, the price could be raised correspondingly and still be competitive for the lighting market. Notably, the municipal utility of Copenhagen charged no less than fifty øre pr. kilowatt-hour at the time.

From the peat argument to the 1907 Electricity Supply Act

Steenberg's argument was not only important as an illustration of the possibilities of high voltage transmission. He also suggested to place the issue on the agenda of the national government by proposing a congress resolution, urging for legislation to support high voltage transmission.[11] The point was that large transmission systems would have to cross land not owned by the power companies, in which case the land owner could obstruct such projects simply by denying access for the establishment of masts. After a Norwegian and a Finnish participant had told the chemical section that the legal possibility to expropriate land for this purpose existed in their respective countries, the resolution was accepted unanimously.

The peat argument, however, could not stand alone. Although the issue indeed was taken up in the political system, the peat argument was more or less abandoned to the favour of other arguments in the process of preparing the desired legislation. Hence, asked by the Ministry of Public Works [*Ministeriet for offentlige Arbejder*] to comment on the congress resolution, the director of the Danish telegraphy directory Niels Meyer thought that the "possibility to use the peat bogs as energy sources must be considered to belong to a rather distant future, and ... is in no way of current interest."[12] But although high voltage transmission would not be as important in Denmark as in for instance the other Nordic countries, he found it likely that high voltage transmission would be used in Denmark, and supported that the accompanying juridical issues should be anticipated in legislation.

Moreover, peat was not mentioned at all in the 1906 report by a government committee chaired by Meyer, which had been appointed by the Minister of Public Works in 1904 to prepare such legislation. This was so despite the fact that the association of peat bog industries was represented in the committee, as well as other interested actors such as several technical societies, the Copenhagen municipality and the traction companies of the Capital. Instead the report recommended legislation for two reasons: On one hand, legislation should address the potential dangers of electricity supply for people and property as well as the disturbance on telecommunication systems. And on the other hand, it should support the expected boom in electricity supply systems, many of which would 'contribute to realize social goals' of producing lighting and power, which made them 'naturally entitled to legal support to overcome difficulties, stemming from the establishment of transmission systems on land not owned by the utility company.'[13] The arguments as well as the Bill proposed by the committee were largely taken over by the responsible Minister, and his Bill was also largely accepted by both chambers of Parliament and enacted in 1907.[14]

The rhetoric for legislation, then, had changed from facilitating the exploitation of indigenous peat resources to supporting the general public interest in the diffusion of electricity in society. In the 1907 Electricity Supply Act, this concern was visible both in the chapter supporting the establishment of transmission lines as well as in the chapter on safety regulations. With regard to the former, it was first stated that power lines could be led across streets and railroads; if the owner disagreed, it was the owner that had to file a protest and the Ministery was to decide. Originally the government committee had striven to exclude cities and towns from this arrangement and thereby exclude competition from private supply undertakings to municipal systems, but the First Chamber of Parliament did not see the need to maintain such a municipal priviledge.[15] And second, the possibility of and procedure for the expropriation of land was specified, thus limiting the property right of land owners opposing to the establishment of transmission equipment (masts and transformer stations) on their land, provided that such equipment was of 'general public interest'.

In addition, although safety regulations would seem to put some constraints on the supply business, also here a main concern was the diffusion of electricity in society. For instance, the introduction of a state concession system through which the State could control the business was rejected because - as the government committee argued - such a system would 'hamper the free and natural developent of these systems.' Instead the Act allowed the Minister to define criteria for the construction and operation of electricity supply systems, and established an Electricity Commission to advise the Minister, register all electricity supply systems in Denmark and exercise inspection. To maintain a flexible system able to respond to technical changes in the field, the technical criteria themselves were not included in the Act, but should be defined and redefined in government notices.[16]

Likewise, the concern to support the diffusion of electricity in society was important for the authorisation of electricians. According to an 1903 installation Act, administrated by the Ministry of Domestic Affairs [*Indenrigsministeriet*], the competence to authorize electricians was delegated to the municipalities. In theory, however, a single municipality could obstruct the construction of a transmission system passing through several municipalities, simply by denying authorisation to the electricians involved. The 1907 Act therefore created the possibility to authorize electricians at a national level to work with such 'dangerous' installations including high voltage transmission. On the other hand, if there were no other electricians than state authorised ones, the electrician expenses of for instance small rural systems would increase and their diffusion be constrained. Therefore, the Act retained the old authorisation system for the 'less dangerous installations', which in practice meant that for instance the rural electricians educated by the D.V.E.S. company could continue their profession. This compromize, which was the main issue of disagreement both in the government committee and in Parliament, remained largely unchanged until the late 1930s.[17]

Electrical engineering and alternating current technology

The peat argument not only provided an incentive for legislation. As early as 1902 it was mobilized by the Polytechnical School in Copenhagen in an application for the establishment of an independent course in electrotechnology to the Ministry of Education. Electrotechnology had been an assisting discipline to other studies at the school since the 1890s, while other, less advanced schools offered brief courses on the subject.[18] Around the turn of the century the latter were expanding their electrotechnical education programs, and the Polytechnical School may have been concerned for its monopoly on higher technical education.[19] In its application, however, it motivated the need for a course in electrotechnology by reference to the threatening lack of qualified engineers, which should facilitate important technical developments in Denmark: It predicted that the state railways might soon introduce electric power, that the postal services would introduce electricity for transport, and finally that power extracted from peat bogs might soon supply "entire regions of the country."[20] Danish engineers might of course seek to supplement their Danish studies in Germany or Switzerland, but the leading foreign polytechnical schools were preparing entry restrictions as they were overrun by foreigners. As a result, Denmark might soon lack competence to participate in the important new field of electrotechnology.

In 1903 the Polytechnical School was granted its course in electrotechnical engineering. During the first years education primarily concerned heavy current engineering (a teacher in signal engineering was first appointed in 1909). Moreover, the technology of district systems was taught from the beginning. Both teachers (from 1906 both appointed professors) were competent in this more advanced field of electrotechnical engineering: Absalon Larsen, who taught laboratory practice as well as theory and measuring technique, had previously worked at the physics laboratory at the Polytechnical School. In addition he had made several journeys to Germany, England and Switzerland around the turn of the century in order to study modern electrotechnology. The other teacher, William Rung, who taught about electrical machines and electricity supply systems, had received all his competence in Switzerland: He had received his engineering degree at the Polytechnical School in Zürich, whereafter he had worked for five years as an engineer at the leading manufacturer of alternating current technology Brown, Boveri & Cie in Baden.[21] From the beginning, Larsen and Rung gave alternating current technology "the weight, which it should have according to its nature", as Rung retrospectively put it.[22] The laboratory was equipped correspondingly, so that the students could study the behaviour of alternating currents and voltages as well as transformers, alternating current motors and generators, and convertors under changing loads.[23]

The theory and practice of alternating current technology, which differed from that of direct current technology in demanding more advanced mathematical understanding (as it included frequency-dependent variables such as capacity and inductivity) was not only made available to new students in electrotechnical engineering. It was also presented to a wider audience in a series of pedagogically intended papers in the periodical *Elektroteknikeren* of the newly established Electrotechnical Society. The papers were written by an assistant at the Polytechnical School and published in 1905 and 1906, and were - as the editor of the journal explained - intended to update the knowledge of older engineers, who had been educated before the alternating current era, so that they could understand future publications on alternating current technology.[24]

The introduction of district supply in North-Eastern Zealand

The failure of the large peat power projects

What, then, happened to Danish peat power? Despite the change of focus from the exploitation of peat resources to more general arguments in the process of legislation, the peat argument was still heard in the discussions in Parliament, and had particular popularity in the popular press.[25] Moreover, immediately after the 1907 Supply Act was enacted, several large and widely publicized projects were designed to exploit indigenous peat electricity. The most visionary project was no doubt a supply scheme designed by the director of the Tuborg-Klampenborg electrical traction company and leading electrotechnical engineer Svend Aage Faber. Faber, who was trained in England and Germany and whose company was the first to introduce district supply in Denmark (see below), suggested to concentrate the production of electricity on Zealand in two or three power stations only. Besides the existing power station of his traction company, new power stations should exploit the energy of the above mentioned *Aamose* peat bog near Holbæk and possibly of the large *Broksø mose* peat bog near Næstved on Southern Zealand. From here, the electricity should be transported by forty and ten kilovolts transmission lines to consumer centres, where it would be distributed by local distribution companies. Simultaneously, the engineering firm Schmidt & Walter designed schemes to supply the respective districts of North-Western Zealand and South-Eastern Zealand from these peat bogs by 20 kV and 10 kV transmission to single transformer stations near manor houses, villages and groups of farms throughout the districts. And finally, an example from Western Denmark includes a private application on a concession to supply the provincial town of Ålborg from a nearby peat bog power station, likewise in 1907.[26]

For different reasons, however, these and similar large projects were not realized. The Ålborg project was rejected by the municipality, which found the supply scheme technically unreliable due to its use of unknown high voltage technology (partly by submarine cable). Instead, the municipality preferred to follow other provincial towns by establishing a municipally run local system. And as described below, Faber's project and Schmidt & Walter's *Aamose* project introduced new and controversial actors on the supply field. The former involved a large limited company to monopolize of power production on Zealand, an arrangement that met decisive opposition from the municipalities which were supposed to participate as distribution companies. The latter involved a new model of joint municipal-county ownership, which failed to cope with internal disagreement. Schmidt and Walter's *Broksø mose* project, by contrast, was to be organized in the well-known form of a consumer owned co-operative society. Yet the project failed to raise capital in a final stage due to the external reasons of a widely publicised scandal in 1908, which caused a general distrust against the co-operative society.[27] In this so-called 'Alberti scandal', the recently retired Minister of Justice Alberti was convicted for having abused his manager position at two co-operative societies - the Zealand farmers savings bank and a leading agricultural butter export firm - to steal large amounts of money during a number of years.[28] This apparent lack of internal control caused a widespread reluctance among banks and other money lending institutes to invest in co-operative societies, at least if they could not give a reliable guarantee for the loans (for instance from a municipality or county). In this situation, the Southern Zealand project had to be postponed.

Soon after the failure of these projects, there was an increasing scepticism to the feasibility of peat energy relative to other forms of energy, and peat energy disappeared out of focus. For instance, a new assessment of the feasibility of a peat bog system on Western Zealand had raised doubts as to the expensive extraction of peat, which would involve 175 workers during five months of the year. In addition, as the drying of peat was a major step in the process, there might be a problem to supply a sufficient amount of peat in very wet years. Consequently, when large district systems actually were built in North-Western and South-Eastern Zealand during the first half of the 1910s, these were not based on peat but on diesel power.

Peat was only used in some smaller systems, and only gained wider importance during the fuel shortages following the two World Wars.[29]

District supply in Copenhagen

Instead, district supply was first introduced in North-Eastern Zealand by two existing electric utilities in 1907. These represented two exemplary types of systems: The Copenhagen municipal supply company reorganized its supply system to supply a large and densely populated urban district, in fact the only large urban district in Denmark: Having close to 400.000 inhabitants just after the turn of the century, Copenhagen was much larger than the other large towns as its twin town Frederiksberg (76.000) and the largest provincial town Århus (52.000).[30] The Tuborg-Klampenborg electric traction company [*Tuborg-Klampenborg elektriske sporvej*], by contrast, expanded its supply business in the mainly rural area North and West of Copenhagen. Renamed the Northern Zealand Electricity and Traction Company [*Nordsjællands Elektricitets og Sporvejs Aktieselskab*, NESA] in 1911, it became one of Denmark's largest utilities supplying most of North-Eastern Zealand save the supply area of the utilities in the Capital.

In Copenhagen, there were two separate motives to introduce district supply. The first was the concentration of production in one efficient power station to improve the existing supply in the most densely populated areas of the city. The immediate cause was a rapid increase in electricity demand in these areas: Following a considerable reduction in electricity prices (from 50 to 35 øre pr. kWh), demand doubled between 1905 and 1908. As a result, the three local systems supplying the inner city, Western city and the Eastern city areas respectively demanded large extensions. Yet the leading engineers of the utility - its director Ib Windfeld-Hansen and plant manager Carl Hentzen - had observed how utilities in some large cities abroad solved similar problems by reorganizing the supply system: The production capacity was concentrated in one large power station, which used large steam turbines instead of steam engines for economical electricity production. These in turn supplied substations with high voltage transmission to reduce transport losses. Windfeld-Hansen and Hentzen then developed two supply schemes for the municipal council. Both maintained and expanded the inner city local system, and both included centralised production for the rest of the municipality. However, while the one scheme supported by Windfeld-Hansen included a new large power station to supply the Eastern and Western city power stations, the other scheme supported by Hentzen suggested to postpone the construction of a new power station and instead concentrate electricity production in the Eastern city power station. From there, electricity should partly be transported to the Western city power station and to the suburbs, and partly be converted locally to low voltage direct current for local distribution.[31] Yet, neither the municipal council nor the subcommittee it appointed to investigate the proposals could decide which scheme to chose. The matter was then postponed, and Windfeld-Hansen and Hentzen were informally told to reach internal agreement first. They then designed an adapted version of the Eastern city power station scheme, but the decision to concentrate production was not taken before 1907.[32]

By then, the introduction of high voltage, alternating current transmission had already been decided for another reason, and the construction of a provisional district system had been on its way for almost a year. This second motive was the urgence of electricity supply of two new Copenhagen suburbs, Valby to the West and and the two Sundby towns Sundbyvester and Sundbyøster on the island of Amager in the South. These suburbs were among the areas absorbed in the Copenhagen municipality in 1901 and 1902.[33] As a result, the establishment of electricity supply networks in these suburbs required approval from the municipal council of Copenhagen to cross municipal roads. However, this situation would change with the 1907 Electricity Supply Act that was on its way. By the spring of 1906, the Copenhagen municipal council therefore foresaw that part of the municipality might be lost to competing utilities: Indeed, in late 1905 a Valby electrician had applied for electricity supply from Copenhagen on behalf of some villa owners. If Copenhagen could not arrange such supply, he asked for permission to negotiate with the nearby supply company of Frederiksberg for supply instead. The Copenhagen municipal council delegated the application to a subcommittee, which advised the council to supply Valby from the Copenhagen power stations as soon as possible. In addition to this affair, a group of land owners from the Sundby towns in the South also approached the municipal council in the spring of 1906; contrary to the Valby electrician, they applied for a concession and monopoly to erect and run their own power station. In addition to these potential competitors, the new district utility that was being established North of Copenhagen might in the future seek to supply the Northern part of the Copenhagen municipality.[34]

In view of this situation, the Copenhage municipality suddenly treated the issue 'with great haste', as plant manager Hentzen retrospectively put it.[35] A scheme to supply the two suburbs was improvised and quickly accepted by the municipal council. According to this scheme, the suburbs would be supplied from the Eastern city power station by means of high voltage, alternating current transmission at six kilovolts. This voltage would be reduced at transformer stations in the suburbs to a consumption level of 127/220 volts, alternating current. As the suburbs only had a modest demand, it was not necessary to install new production equipment at the power station; instead, high voltage electricity could temporarily be produced by using convertors and a step-up transformer to convert a minor share of the produced low voltage, direct current into high voltage, alternating current. The new provisional district system was operational by the late summer of 1907, when it co-existed with the two independent local systems in the inner city and the Western city.[36]

In the following years, the rapid expansion of the district system followed both motives: On one hand, concentration of production was finally carried through to supply the densely populated city centre. In 1908 the scheme mentioned above was implemented: The production capacity of the Eastern city power station was tripled with two large (2.5 megawatts) turbogenerators - the first turbogenerators in Copenhagen, and a high voltage line was build to the Western city power station four kms away. Here, convertors changed the incoming high voltage, alternating current to low voltage, direct current for distribution.[37] Likewise, in 1909 the municipal council accepted a scheme to supply additional electricity to the inner city power station. As the electricity demand of this area stagnated relative to the areas around the Eastern and Western city power stations, however, the utility first established a link to the inner city power station in 1913.[38] Notably, in terms of capacity these transmission systems were much larger than those supplying the suburbs: For instance, while the suburban transformers in the provisional installation of 1907 had a capacity of 152 kilovoltampères (kVA), the conversion station at the Western city power station of 1908 had a capacity of three megawatts, almost 20 times as much.[39]

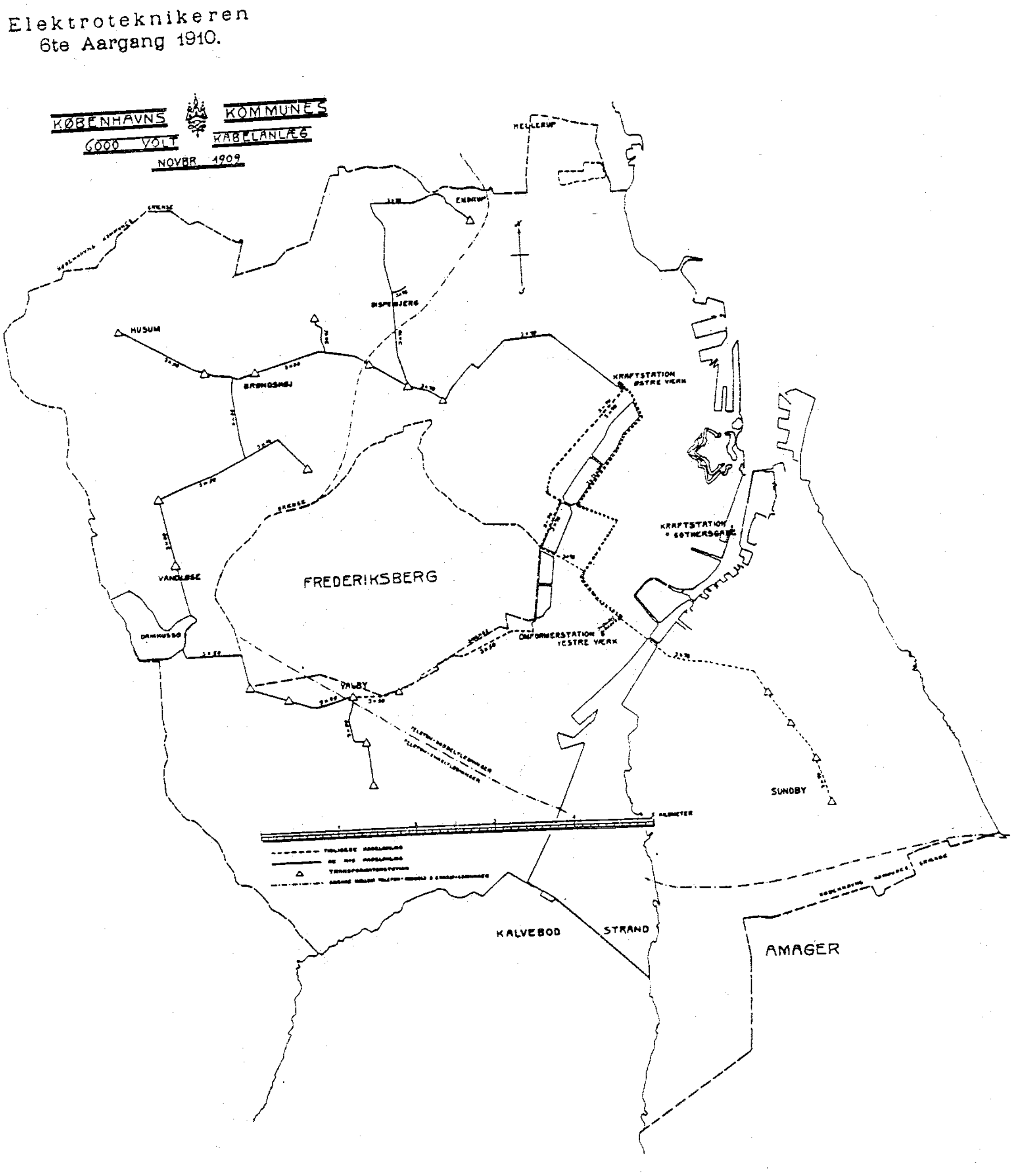
On the other hand, also other suburbs were included in the district system: In 1909 the municipal council accepted a project to supply the suburbs in the North and West of the city by means of a transmission ring with few offshoots, including fourteen transformers (500 kVA), fed by the Eastern city power station. And in 1914 the Copenhagen utility took over the supply of the rural municipalities on the Southern part of Amager by means of a transmission ring including fourteen transformers (175 kVA). The form of a ring was chosen to increase the security of supply: As transformer stations on the ring were connected from two sides, supply could be maintained even though one connection broke down. By 1915, then, Copenhagen had a large district system supplying most of the municipality as well as other municipalities from the Eastern city power station. Notably, high voltage transmission had enabled a significant increase in its supply area: While the reach of the local systems had been only a few kilometres, it now supplied consumers at distances up to fifteen kilometres.[40]

The concentration of production in the district supply system of Copenhagen culminated in 1920 with the inaguration of a new, very large power station at the seaside outside the city.[41] This large (nineteen megawatts) and favourably situated power station, named after the Danish scientist Hans Christian Ørsted because of the centenary of his discovery of electromagnetism, took over most of the electricity production of the municipality. The Western city power station became a pure conversion station, the inner city power station maintained some of its production machinery to provide back-up and peak capacity, while the Eastern city power station became a combined conversion and production station.

The Northern Zealand district system

For the Tuborg-Klampenborg electric traction company, a limited company owned by the Copenhagen traction company and thereby mainly owned by the German firm *Gesellschaft für elektrische Unternehmungen* in Berlin, the motive to introduce high voltage, alternating current transmission followed its increasing role as an electricity supply company of a much less densely populated area.[42] The company had been founded in 1902 to provide electric traction along the seaside boulevard North of Copenhagen. Its track would lead from the Tuborg harbour at the Northern border of the Copenhagen municipality to Klampenborg; a scarcely populated area including only some small towns, but a popular outing resort for the inhabitants of the capital. The traction line was constructed during 1903, and electricity was provided by the company's new power station at the small seaside town of Skovshoved. Soon after the company began operation on part of the trajectory in 1903, however, it received requests for electricity supply for lighting and motors by private consumers near the boulevard. From 1904 the company supplied several consumers, which could be reached without crossing any municipal or parish roads. These were consumers on the boulevard (which was owned by the Copenhagen county, which had given permission to use it for electricity transport) or privately owned sideroads. Motors along the boulevard were supplied with 550 volts direct current taken directly from the traction wires, while lighting was provided at 220 volts direct current to a small area from a substation at the tramway depot near the Copenhagen municipal border.[43]

As the load increased vastly the following years, electricity supply became a more important activity of the company, which then actively sought to extend its supply area. When inhabitants of the rural municipality of Gentofte (directly North of the Copenhagen municipal border) desired electricity, the company obtained permission to use municipal roads from the parish council; in return, it should establish a traction line to a part of the municipality, the urbanisation of which lagged behind. The leading engineers - director Svend Aage Faber and engineer Aage Rørbye Angelo - opted for high voltage transmission as 'the most economical way to construct a widespread supply system', as Angelo retrospectively put it.[44] After a study tour to the Neckarwerke in Southern Germany, which was satisfied with its alternating current system including ten kilovolts transmission and 380/220 volts distribution, they decided to use the same system in Denmark. The district system was operational in the spring of 1907, slightly earlier than its counterpart in Copenhagen. And like in Copenhagen, high voltage was first produced by means of convertors, before the



Legend: ▬ = *Eastern city power station,* --- = *Transmission cables established 1907-1908,* — = *Transmission cables established 1909,* ▵ = *Transformer station.*

Figure 4.1: The district system of Copenhagen by 1910. Production was concentrated in the Eastern city power station ['kraftstation østre værk']. By means of high voltage (6 kV) transmission, it was then transported (1) by a Southern line to the Western city power station ['omformerstation vestre værk'] and the Sundby towns on Amager, and (2) by a transmission ring to the suburbs Valby, Vanløse, Brønshøj, Husum, Bispebjerg and Emdrup. The inner city power station ['kraftstation Gothersgade'] was an independent local system until 1913. Source: Rathlou 1909, scheme 1.

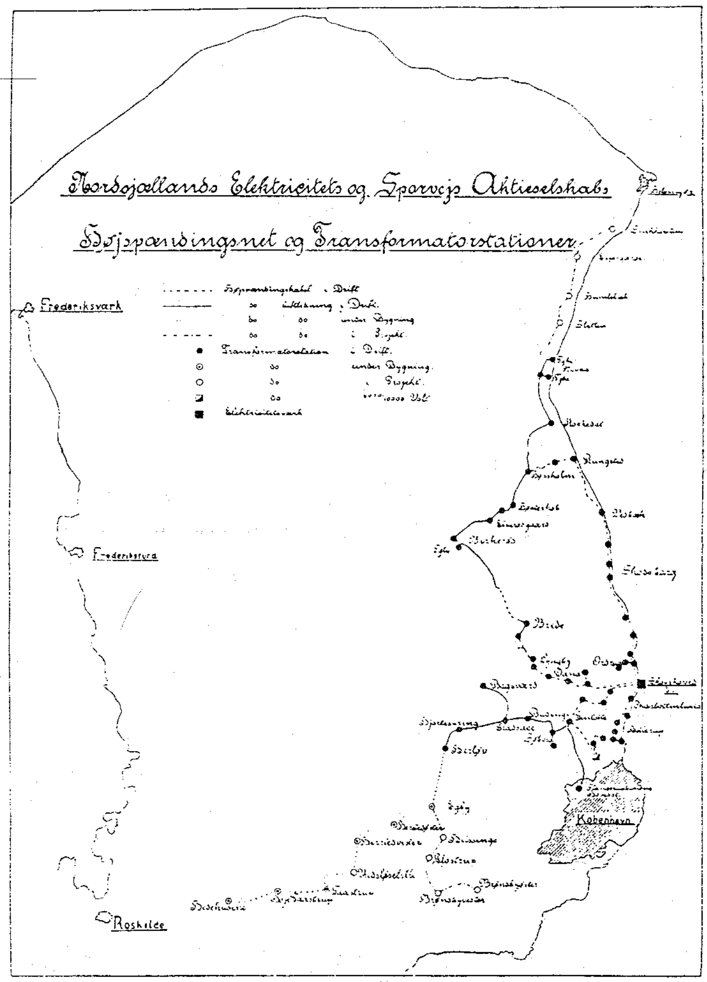
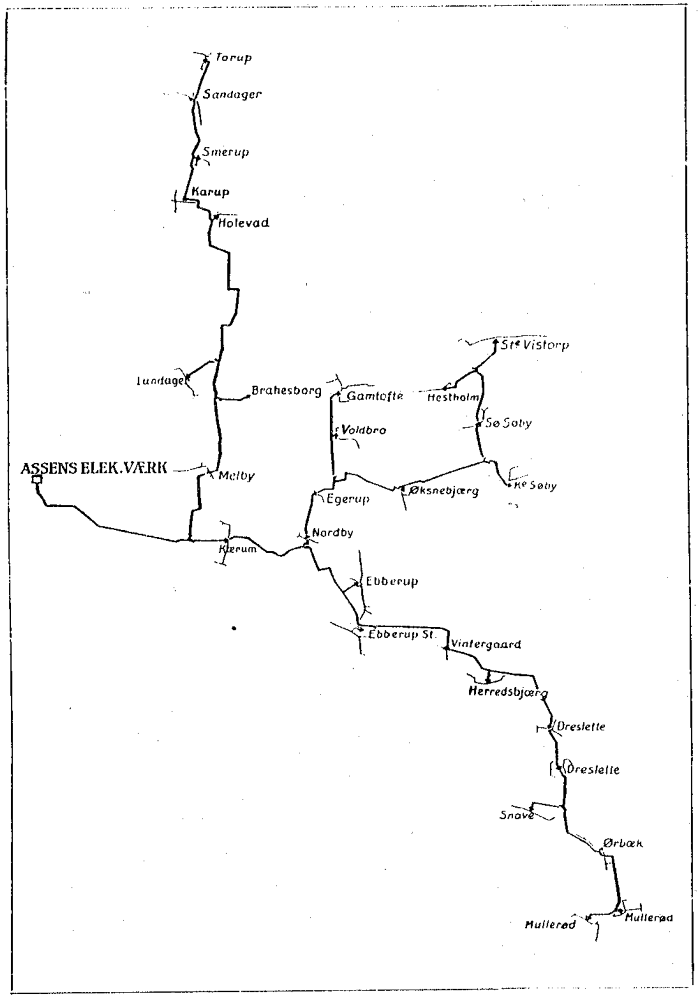
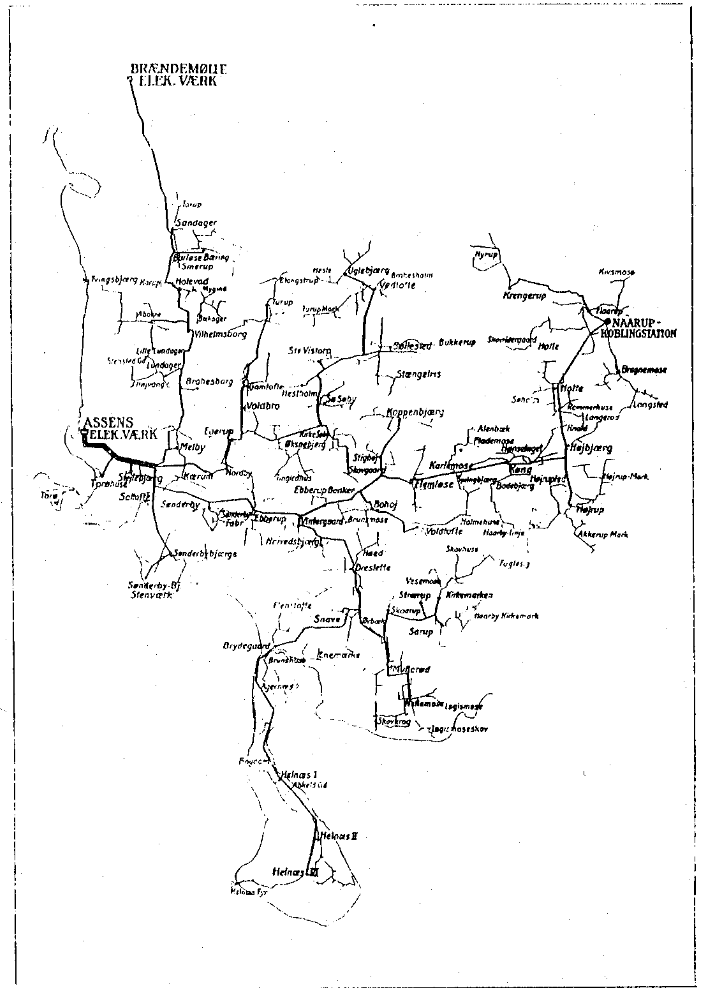


Figure 4.2: The rural district system of the NESA company, North and West of Copenhagen - [København], in 1911. Legend: ■= Power station; ● = Transformer station; —— = High voltage line; ---- = High voltage cable; ······ = Planned high voltage line. Source: Elektroteknisk Tidsskrift Vol. 16 (1911/12), 13.





Legend: □ = power station, ▲ = transformer station, thick line = transmission (10 kV) line, thin line = low voltage (380/220 V) line

Figure 4.3: Supplying the hinterland outside the municipal borders: The town-based district system of Assens in 1911 and 1935. The 1911 system included a 200 kW power station and had a reach of some thirteen kilometres. Source: Beierholm 1935, 19 and 55.

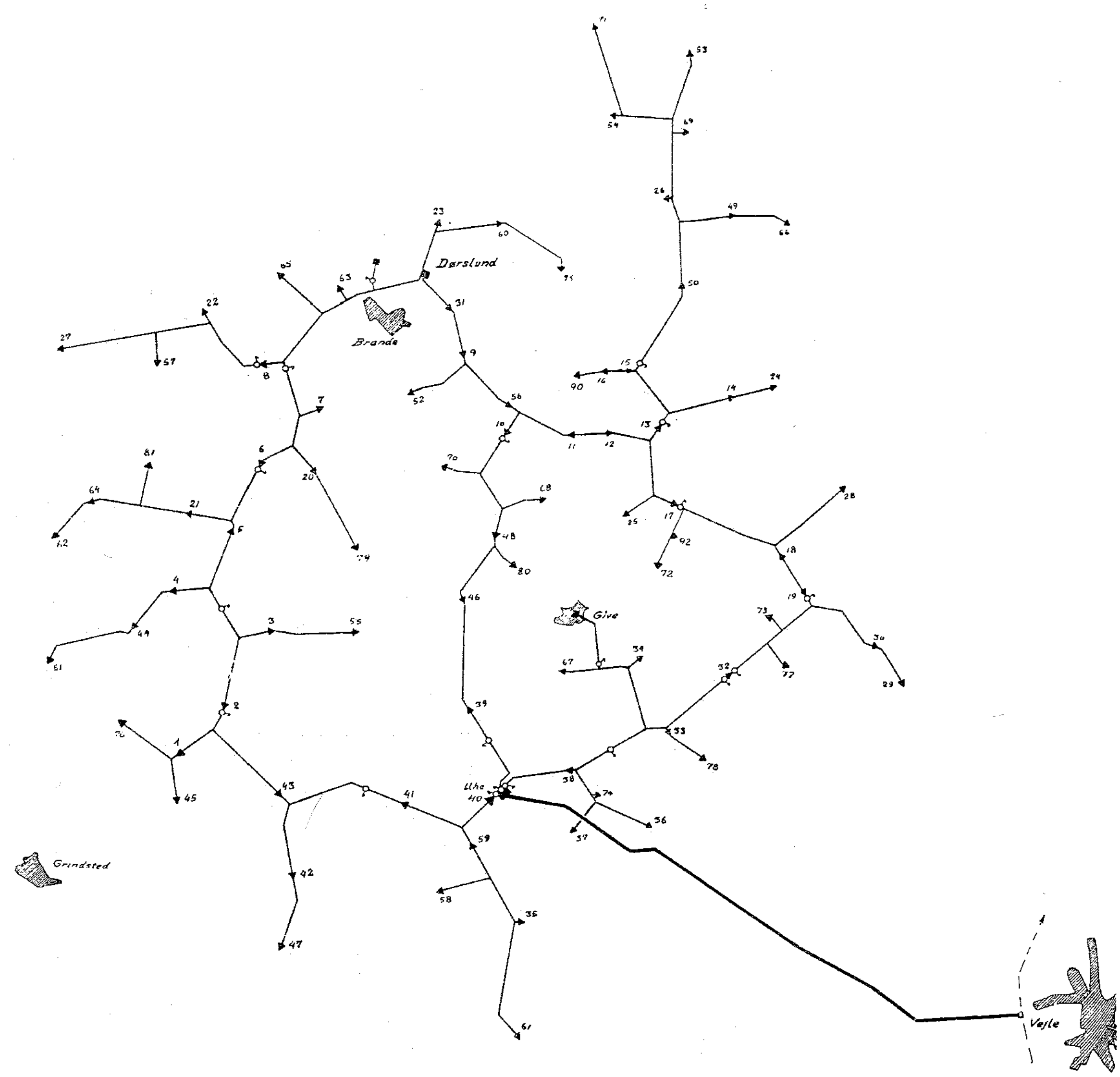


Figure 4.4: The hydro powered MES system in Mid-Jutland in 1946. The original transmission network consisted of two lines, leading from the power station at Dørslund to the South-East and the South-West respectively. In the second half of the 1920s these lines were mutually connected, thus forming a ring (by 1931 the system had 50 transformer stations). Finally, a connection to the town utility of Vejle and thereby the Jutland grid was established during the Second World War. Source: Jørgensen 1946, 50.

production machinery was renewed with two large (five hundred kilowatts) turbogenerators later the same year.[45]

In the following years, the company actively expanded its supply system. In the beginning this took active propagation, for instance by arranging discussion meetings, demonstrations and slide shows to convince the inhabitants of nearby districts of the benefits of electricity. Soon, however, growth became so fast that agitation was unnecessary. Every year several new municipalities were included in the transmission network. In 1909, for instance, the rural municipalities of Lyngby, Gladsakse and Vedbæk were supplied after agreements with their respective parish councils; in 1910, the rural municipalities of Rungsted, Hørsholm and Birkerød were added (figure 4.2).[46] By the beginning of the First World War, the system supplied some fifteen factories and more than fifty villages.[47] By the end of the war, it supplied some twenty factories, some seventy villages and supplied additional electricity to local electricity supply systems in the village of Holte and in the urban municipalities of Helsingør (Elsinore) and Roskilde. By 1920 the transmission system was one of the largest in the country with a maximum supply distance of some fifty kilometres.[48]

The actors of district supply

The actors: An analysis

From the first introduction of high voltage, alternating current electricity transmission in 1907, the new technology spread rapidly across the country. By the beginning of the First World War there were already some twenty-six utilities using the new technology (see also figure 3.2 in the previous chapter). A decade later the number of Danish district systems had stabilized around fourty-four systems, and did not decrease significantly until the 1950s.

Who, then, were the actors that established and exploited these systems? According to an analysis of the electricity supply statistics, out of twenty-six district supply systems by the beginning of the First World War, twelve (46%) were owned by a municipality, nine (35%) by a co-operative society and five (19%) by limited companies or private entrepreneurs. And when the diffusion process was nearly completed about a decade later, out of forty-four district systems (three systems using high voltage, alternating current transmission are for the purposes of this study included under centralized supply) more than half (52%) was owned by a municipality, a quarter (25%) by a co-operative society, and a quarter by a partnership (16%), a limited company or a private entrepreneur (together 7%).[49]

Moreover, if one again classifies these district systems as town-based and rural systems after their location of the power station in towns or on the countryside, it is clear that two main kinds of actors exploited these two types of district systems (table 4.1). These were the same actor groups that exploited urban and rural local systems: In 1923/24, most district systems (thirty-one) were town-based. Their large majority (twenty-three) had direct municipal ownership. Of the remaining eight systems, six were operated indirectly by the municipality through a partnership - or in the single case of the Jutland town Odder a co-operative society[50] - with consumer associations in the hinterland. In these cases, the partnership operated the power station, while the municipal utility and the consumer association stood for transmission and distribution in the municipality and the hinterland respectively.

As a result, only two town-based district systems did not have direct or indirect municipal ownership: The system supplying the urban - mostly labour quarter - habitation of the rural municipality of Sct. Hans just outside the large Odense municipality was exploited by the Danish electrotechnical manufacturing firm Thomas B. Trige, while the system in the town of Assens on Funen was exploited by the large Swedish electrotechnical manufacturer Allmänna Svenska Elektriska A/B (ASEA) on a concession from the municipality. In the latter case, however, the municipal council retained influence in the company strategy by demanding the inclusion of local representatives in the company board, including a representative from the municipal council.[51]

Table 4.1: Ownership of Danish district systems in 1923/24[52]

	Municipal	Partnership	Co-operative society	Other	Total
Town based	23	5	1	2	31
Rural	-	2	10	1	13

With regard to rural district systems, out of thirteen of such systems existing in 1923/24, ten were owned by co-operative societies founded by rural consumers. None were owned by municipalities, while three district systems were owned by a partnership, limited company or private entrepreneur. As in the case of rural local systems, however, these latter utilities might in practice function as co-operative societies in the sense that they were mainly owned by or had decisive influence by consumers. Often, the alternative ownership form was applied merely to ease the process of raising capital. This was particularly relevant for the earliest systems established between 1909 and the beginning of the First World War, when money lending institutes still distrusted co-operative societies following the finance scandal causing the failure of the peat bog project in Southern Zealand mentioned above.

The further developments on Southern Zealand are illustrative. Several years after the failure of the peat power scheme, the project was reinitiated as a diesel power project and was given the form of a limited company (operational in 1914). This meant that at least half of the capital had to be raised by shares, the rest through bonds issued by the company. However, this was merely a financial strategy suggested by the consulting engineer Frederik Krebs: For the consumer-representing committee organizing the system - including representatives from all parishes to be supplied, the goal was to run the company as a co-operative society as far as possible. To start with, this meant to have the company owned and financed by as many consumers as possible, and 'if possible by all.' Thus the committee sought to sell the shares and bonds to the consumers, who were attracted with discounts on their electricity purchases relative the amount of bonds or shares purchased. In addition, the committee worked out a set of rules to prevent control by few over the many: Large capitalist enterprises were discouraged to take over the company as consumer share holders could buy additional special shares with a three percent higher annual yield than normal shares (which made the shares more valuable for consumers than for non-consumers), and in addition the annual yields were limited to a maximum. In addition, concentration of shares in the hands of one or few consumers was discouraged by ensuring that a larger share capital did not give a proportionally larger voting right, while share holders could at most be authorised to vote for two other share holders. Finally, with regard to the organisation of the company, the company board consisted of representatives of the consumers organised by parish. The board in turn elected the executive committee. Thus, also in this respect the ideal of the co-operative society was approached.[53]

Also other ownership forms were used in this creative way. For instance, when the other failed peat bog project - the North-Western Zealand district system - was reinitiated as a diesel power project (operational in 1913), it was exploited by private entrepreneur Otto Meyer, who run an electrician firm. The planning as well as operation, however, happened in close co-operation with a consumer committee. Also here the key issue was a financial plan; in this case, the parties agreed that three-quarters of the capital was to be raised by the consumers, the remaining part by the entrepreneur. The consumers had the right to take over the system from the entrepreneur by raising the last part, which they did at the end of the First World War. With regard to the operation, a consumer committee represented consumer interests towards the owner.[54]

Finally, also the form of a 'partnership' could be used, as in the case of the small rural district system at Brande (rather isolated in the middle of Jutland in figure 3.2). This was not a traditional partnership between a few large actors, say a municipality and a co-operative society as in the case of the partnerships exploiting town-based district systems. Instead, the utility was founded in 1909 as a partnership of some seventy consumers. Part of the capital was then raised as entry fees from the partners, while the rest was loaned at an agricultural savings bank under collective liability.[55]

From the mid 1910s, however, rural district systems were as a rule plainly founded as consumer owned co-operative societies, which barrowed capital at local banks or insurance companies. As a rule, this was possible - or at least cheaper (giving a lower interest rate) if the society obtained a guarantee for the loan, typically from the rural municipalities covered by the supply system. The consumers were then collectively liable towards the municipality. Although some municipalities were difficult to convince, many saw this as an acceptable way of indirect support to the general welfare in their municipality.[56]

Non-actors I: Private enterprise

The conclusion is justified, then, that district systems in Denmark were primarily exploited by traditional actor groups on the public electricity supply market. The municipalities (possibly in co-operation with consumers in the hinterland) were the key actor group with regard to town-based district systems, just as they were responsible for the exploitation of urban local systems. And rural consumer associations in different organisational forms were the key actor group with regard to rural systems, just as they exploited the large number of rural local systems. Private enterprise largely lacked as an actor group, while it is noteworthy that no new public actors transcending the municipal level entered the field to exploit the new large scale supply technology.

With regard to private enterprise, it was already observed in the previous chapter how the municipalities had taken control of town supply. In almost all cases of town-based district supply, the municipality had taken over or started a local system before district supply was taken up. As a result, also the town-based district systems were directly or indirectly controlled by single urban municipalities. Notably, neither of the two exceptions of industrial ownership mentioned above was the result of aggessive policy by the large capitalist enterprises. In the case of Assens, it was the municipality that had aproached and invited the ASEA company to propose a design scheme, not vice versa. The issue had been raised in the town council after an application for a concession by a private entrepreneur, and although the municipality exceptionally decided not to exploit a system itself, it would neither risk competition with the privately owned gas company, which held a fifty-years concession. The municipality instead invited several firms to compete for the concession on rather harsh terms. For instance, the municipality did not only require representation in the utility board and a limitation on electricity prices, but also demanded five percent of the gross turnover. Even though ASEA accepted these conditions, it could not run the utility with a profit, and its income stemmed exclusively from the sale of ASEA equipment from the Swedish mother company to its Danish subsidary. And in the case of the Thomas B. Trige company's supply of the rural municipality bordering Odense, the company did not particularly compete for obtaining supply areas. Instead, the problem was that the conservative municipal council of Odense had neither desired to absorb the area - which lodged labour quarters as well as Trige's and other factories - in the municipality nor to supply it with electricity from the town supply system.[57]

In addition, several attempts to establish new systems exploited by large, financially strong private enterprises failed. The most discussed of these was the large scale, partly peat-powered system designed by director Faber of the Tuborg-Klampenborg electrical traction company in 1907, which was also mentioned above. The idea was that one large limited company, mainly owned by two large banks, should run the production and transmission part of the system, which as should supply all of Zealand. Local distribution was left to urban municipalities and rural co-operative societies. This organisational model thus depended upon co-operation from the urban municipalities. However, with the increasing social-democratic influence in the urban municipal councils (particularly after universal suffrage to municipal councils was introduced in 1908) as well as the increasingly accepted model of municipal socialism across the political spectre, municipal councils increasingly rejected the idea of monopolization of electricity supply by a large capitalist enterprise. Although Faber's company had purchased the *Aamosen* peat bog, it then abandoned the project in view of this opposition. As professor Rung complained, the supply case "would be served best in the hands of one financially strong company, ... but the time-spirit demands municipal supply."[58]

In few other cases, initiators trying to establish a large scale district system attempted to contract large Danish and foreign firms to finance and exploit these systems. For different reasons, however, also these attempts failed. For instance, after the peat power project on North-Western Zealand had failed in 1908 (see below) and before the diesel power system was established in 1913 (see above), local agricultural organisations and rural municipalities in the area attempted to save the project as a co-operative society. Like in the case of the Southern Zealand peat project, however, the organizing committee failed to raise capital due to the sudden distrust in co-operative societies following the Alberti scandal. The committee then approached the ASEA company, which accepted the proposition in return for a 40-years concession. Although this concession was approved by both municipal and county authorities, however, the responsible Ministry replied that it rejected all concessions to foreign firms following recent problems involving the concession held by an English firm [*Det danske Gascompagnie*] operating the Frederiksberg gas works. The committee then tried to interest the large Danish ship yard and machine works Burmeister & Wain, which had a stake in electricity supply through its production of diesel engines. Although its director was positive, the large agricultural bank [*Landmandsbanken*] behind the firm was negative, and the project was abandoned once again.[59]

A similar initiative to attract the Danish division of the German firm AEG to exploit a district system supplying the entire island of Lolland in 1909, initiated by manager Faye of the Nakskov sugar factory, failed due to opposition raised in the area. According to an actor, who claimed to have participated in sabotaging the scheme, the plan might have succeeded if Danish industry and handicraft had been involved instead of a foreign firm. Now local actors decided to raise opposition instead, which was easily achieved particularly among the farmers; for Faye and AEG had counted on the manors for rural support, and largely 'neglected the strength and self-determination of the common farmers', which instead were mobilized by the opponents of the system.[60]

Finally, also the private owners of the Tuborg-Klampenborg electric traction company (now NESA), the main example of economically successful private exploitation of district supply, left the scene during the mid 1910s. As mentioned above, this utility was a subsidiary company of the Copenhagen electric traction company, which was mainly owned by the German firm *Gesellschaft für elektrische Unternehmungen*, while two large Danish banks held a minor part of the shares. When the Copenhagen municipality took over electric traction in Copenhagen in 1911, the Copenhagen electric traction company was to be liquidated. By purchasing the shares of the German company, the Copenhagen municipality would own the majority (63%) in the Copenhagen traction company but also in the NESA utility. While negotiations between the Copenhagen municipality and the German firm were delayed due to disagreement on the value of the company (first resolved by the Supreme Court in 1916), however, the Gentofte municipality - where NESA was based - succesfully negotiated with the German firm and purchased the traction companies instead. Thus it gained control with NESA, and sold the Copenhagen traction material to the Copenhagen municipality. As the Copenhagen county bought out the two large Danish banks few years later, NESA had become a limited company owned by a municipality and a county.[61] Hence, when Kay Emun Rager, editor of the electrotechnical journal *Lys of Kraft* discussed the organisation of the Danish electricity supply business in 1919, he could conclude that "private initiative has tried, but either has been beaten or has retreated voluntarily, as it noticed head wind."[62]

Non-actors II: New public bodies

In addition to these failed projects to establish systems owned by large industrial firms, there were several attempts to establish new forms of public power companies at a supra-municipal level. However, with the exception of the peculiar situation of the NESA company, also these projects failed. These initiatives for instance included the original peat power scheme for North-Western Zealand in 1907 and 1908. In this case, the three urban municipalities of Kalundborg, Slagelse and Holbæk and the county of Holbæk appointed a joint committee to study the possibility of exploiting a a combined intermunicipal-county power station, based on energy from the large *Aamose* peat bog. The engineering firm Schmidt & Walter worked out several supply schemes, either merely supplying the three towns, or supplying the towns and part of their hinterland, or supplying the towns and their entire hinterland. Yet the project stranded on negotiations between the urban and the rural actors, who could not agree on different electricity prices for the towns and the hinterland. The urban municipalities then decided to exploit local systems instead: In Slagelse the municipality took over the privately owned supply company and build a new direct current power station (1908), while the municipalities in Kalundborg (1908) and Holbæk (1911) decided to establish completely new local systems. The Holbæk county council then decided to redesign the plan to supply the rural municipalities only, but subsequently abandoned the project, after a council member fearing the financial risk for the county successfully managed to raise doubt on the feasibility of the peat power scheme.[63]

In a similar way, the municipal council of Helsingør had in vain attempted to establish an intermunicipal power system for North-Eastern Zealand. It had invited the councils of some sixty, mostly rural, municipalities in the area to discuss exploitation of such a large system; also here a committee was formed to investigate the matter, and professor Rung of the Polytechnical School was hired to design a supply scheme. But the project failed, and while most rural municipalities in time were supplied by the growing NESA company, the urban municipalities of Helsingør (1911), Hillerød (1909) and Frederikssund (1914) build their own local systems.[64] In this early period of district supply, then, the establishment of inter-municipal or county owned utilities generally failed.

The diffusion of town-based district systems

District supply in municipal organisations

What, then, caused the two actor groups of urban municipalities and rural consumer associations - sometimes in joint exploitation - to establish district supply systems? For both actor groups, it is remarkable that journals and interest organisations paid relatively little attention to the innovation of district supply during the diffusion period, and therefore were hardly able to shape a common attitude towards innovation. This is particularly remarkable for the market-town association, as more than one third of the eighty-ninety Danish urban municipalities had a town-based district system by the early 1920s, which were primarily exploited by the municipalities. For municipal interest organisations, however, electricity supply would only become a big issue with the fuel crisis of the First World War, the foundation of the association of urban municipal utilities in the 1920s and particularly the centralisation of electricity production in the 1940s and 1950s.

Still, the municipal utilities were amply informed on developments elsewhere in the country through the existing information infrastructure. On one hand, municipal newsletters informed municipal council members on the establishment of district supply systems in other municipalities, and in some cases of the arguments used and the negotiations with consumers involved. In one larger article, for instance, an assessment of the advantages of direct and alternating current systems by Holger Bache, previous engineer at the Frederiksberg electric utility and now professor in mechanical engineering at the Polytechnical School, was reprinted. The investigation had been requested by the Silkeborg municipality during its decision process on a municipal electricity supply system; but the newsletter reprinted it because of its 'amount of considerations and information ... of particular importance to our readers.' Although Bache unambiguously recommended local supply as the optimal choice for small supply areas, he also clearly stated that the choice of system was 'a pure matter of distance', where alternating current was preferable, if the system exeeded a radius of two kilometres at several points.[65]

In adition, the issue of district supply was taken up occasionally in the newly founded association of urban plant managers [*Foreningen af Elektricitetsværksbestyrere i Danmark*, 1909]. This was not a forum for politicians to discuss municipal policy options, but for plant managers mostly (in the beginning exclusively) from municipal utilities to exchange experiences in the new and rapidly developing field of electricity supply. At its annual meeting of 1913, for instance, members of the association discussed negotiation strategies and organisational forms to enroll consumers in the hinterland in the town supply system by means of district supply.[66]

Three objectives for introducing district supply

Still, the decision for municipal supply companies to initiate district supply very much had a local logic. A study of the individual municipal utilities which initated district supply suggests that there were at least three objectives in the different cities and towns.[67] First, for the utilities in the capital area the objective was to simply supply the entire city by expanding the system as well as to anticipate the large electricity demand in the load centres by centralizing the system. This is not surprising, as the two capital utilities of Copenhagen and Frederiksberg had to supply the largest municipalities in Denmark. The introduction of district supply in Copenhagen from 1907 has been described in detail above. In Frederiksberg, district supply was introduced for similar reasons already the year after. Also here the objective was to expand supply to the entire municipality, while at the same time concentrating production in order to anticipate the expected huge growth of the electricity demand: By extrapolation, the utility calculated with a linear increase in population from some ninety thousand to two hundred thousand inhabitants by 1950, provided that all villa quarters were replaced by multi-stored appartment buildings (which proved a considerable overestimation). Supposing that each appartment would use the currently normal amount of electricity (obviously a considerable underestimation), a maximum demand curve showed that the local system supplying the town already lacked capacity. Therefore, as utility director Carl Winsløw put it, "the electricity supply system had to be designed so as to meet the demand, even if developments went as fast as they possibly could."[68] To this goal, an entirely new power station was build - the largest in the country after those of the Copenhagen municipality, producing alternating current at six kilovolts for transmission as in Copenhagen. Simultaneously, the city was devided into districts: The local power station supplying the central district was turned into a transformer and conversion station (yet it continued to produce traction electricity), while new transformer and conversion stations would supply a Northern and an Eastern district. The still scarcely populated Western part of the municipality would be supplied directly with alternating current.[69]

Second, with regard to the provincial towns, in several cases high voltage, alternating current transmission was introduced originally to supply new large power consumers, possibly at some distance from the local power station or requiring large amounts of electricity relative to the total production of the utility. For the electric utility, the rationale of including large stable power consumers in the system was to compensate for the daily, weekly and annual fluctuations of the demand of lighting consumers and create a more regular load, which in turn would facilitate a more optimal exploitation of the generating capacity (and thereby a higher return on investment). Already Thomas Edison knew that the regularity of the load and the maximum utilization of the generating capacity were decisive economical factors of an electric utility. Moreover, in the 1890s both aspects were summarized in the now well-known concept of the 'load factor', the ratio of the average load and the maximum generating capacity during a specific period of time.[70] A high load factor thus indicates a high exploitation of the invested capital. While the load factor became a central concept in the management of electricity supply systems in the United States and Great Britain, in Germany the comparable concept of 'utilization time' [*'Benutzungsdauer'*] of the power station was used, which is the ratio of the annual production in kilowatt-hours and the maximum generating capacity (differing from the load factor by a factor of 8760 annual hours in the numerator). For German power stations around 1905, this utilization time varied beteen three hundred and two thousand hours of the generating capacity.[71]

In Denmark, the argument was for instance presented by Copenhagen plant manager Oscar Engholm during the discussion on the economy of small electricity supply systems in the Electrotechnical Society in 1905. Engholm pointed out that the modest economic returns of small power stations compared to those of larger power stations were not only caused by their relatively large investments and running expenses (per kWh), but also by their poor exploitation of the production machinery, which Engholm expressed after German example in terms of the utilization time: Danish municipal systems in smaller provincial towns, for instance, had a utilization time of some 400-600 hours of the generating capacity (i.e. a load factor of 0.05-0.07). By contrast, the large Copenhagen system had a utilization time of some 1300 hours (a load factor of 0.15), and thus exploited its capacity much better. According to Engholm, this low utilization time of the power stations of provincial utilities followed the importance of the varying electric lighting demand. To increase the utilization time, he suggested to complement the lighting demand by a motor demand from for instance brick works, which particularly operated in summer time (when drying costs were low), when the lighting demand was lowest. Alternatively, an obvious strategy for municipalities could be to electrify the municipal water works, and supply them from the electric utility. This would be advantageous for the utility, because water works had a large utilization time and a maximum demand in the summer-time, while the introduction of electric drive would also improve the technical - and possibly also the economical - performance of the water works.[72]

This strategy was indeed used in several towns, and sometimes coincided with the introduction of high voltage transmission. For instance, the municipal utilities of Horsens (1908), Hjørring (1916) and Nykøbing on Falster (1916) first introduced high voltage transmission to supply their newly electrified water works, which were situated at some distance from the central power station. In the latter case, for instance, the municipal utility operated a 2 x 110 volts direct current distribution system, which had a reach of about two kilometres by the mid 1910s. When supply to the waterworks at some three kilometres from the power stations was taken up, the utility decided to use alternating current of three kilovolts for transport. At the water works, the high voltage, alternating current was again converted to direct current for running the pumps.[73]

Other utilities connected other kinds of large consumers. For instance, the municipal utility of Middelfart introduced high voltage transmission in 1912, after the Danish State Railways had requested supply to a new railway station in a small nearby town of Strib. As the distance from Middelfart was some nine kilometres, the railway station could not be supplied by the 440 volts distribution system of the Middelfart municipal utility, which then adapted its local electricity supply system with alternating current transmission at four kilovolts. And the municipal utility in Vejle introduced high voltage transmission in 1919 to meet a request for alternating current supply by the local flour factory, which in addition to providing a regular and large load (demanding about half of all the electricity sold by the utility in 1920) agreed to participate in financing the necessary equipment. In this case, this involved a 400 kVA alternating current generator at the power station, few kilometres of six kilovolts transmission line from the power station to the factory, and a 500 kVA step down transformer at the factory premises.[74]

Finally, a third and perhaps most important objective of the municipal establishment of district supply was expansion of the supply area outside the municipal borders to the rural consumers in the hinterland. For many municipal utilities, supply to the hinterland was the primary objective to introduce high voltage transmission. But also for those utilities, which had introduced high voltage transmission to supply large power consumers, supply of the hinterland rapidly became a large activity: The Horsens and Middelfart utilities mentioned above from the very beginning supplied also the general public in the villages near the water works and the station, which they were to supply, while the Hjørring and Vejle utilities took up supply to their respective hinterlands in the 1920s. The case of the Nykøbing Falster utility, which did not supply its hinterland in order not to compete with the large rural district system on Falster and thus only used high voltage transmission exclusively to supply urban consumers (the water works, the harbour), was a rare exception.[75] As the expansion of municipal supply systems into their hinterlands was the primary model for rural electrification in large parts of Denmark, this development deserves some closer investigation.

Expansion into the hinterland: Initiatives and decisions

The first utilities to take up large-scale district supply in order to supply the hinterland were the utilities in Fåborg (1910) and Assens (1911) on South-Western Funen (the two systems West of the most Southern system of Svendborg in figure 3.2). In the case of Fåborg, expansion into the hinterland followed the expansion strategy of the municipal utility: Already one year after the municipal utility established a local system to supply the town itself, it approached the parish councils of several surrounding rural municipalities with an offer for electricity supply. In this proposal, the rural municipalities would receive electricity from the Fåborg transmission network, but finance and exploit local distribution networks themselves.

When the rural municipalities were unwilling to participate in any investment, however, the utility investigated the feasibility of building and running the entire system itself - from alternating current production at the power station to supply of the single consumer. The D.V.E.S. company was contacted to contract rural consumers, and professor Rung from the Polytechnical School was engaged to design the supply scheme and calculate the economic feasibility of the system. When Rung's calculations showed that the system would give annual returns of some fourteen thousand DKK on an investment of 122 thousand DKK (about half of which for the transmission system and transformer stations), the municipal council agreed to the scheme, and the district system became operational in 1910. At its inaguration, it supplied sixteen transformer stations (149 kVA), all situated in villages with less than five hundred - and often less than one hundred - inhabitants.[76] And in the case of the privately owned utility of Assens, the only difference is that this system was started as a district system from the beginning, whereas almost all other Danish town district systems were expanded local systems. At its inaguration, the Assens system supplied some twenty villages in the hinterland by twenty-six transformer stations. These were connected by four main transmission lines (figure 4.3). In 1912, the Fåborg and Assens systems had a reach of sixteen and thirteen kilometres respectively.[77]

The initiative for expanding the supply area to the hinterland, however, only sometimes came from the utility, that is, the plant manager or the consulting engineer. In other cases, it stemmed from the consumers in the hinterland. The interest in electricity supply in these rural areas followed, as described in the previous chapter, a widespread agitation for the advantages of the electrification of agriculture. Moreover, like in the establishment of rural production systems, influential inhabitants often involved local interest organisations or assembled associations of potential consumers. In the case of the Jutland town Fredericia (the system closest to Funen on figure 3.2), for instance, the issue of electrification of agriculture was raised in 1912 by a member of the agricultural society for Fredericia and surroundings. The society then arranged a special meeting on the issue, and thereafter approached the electricity committee of the Fredericia municipal council with a request for supply of the hinterland by means of high voltage transmission.[78] In other cases, the initiator invited potential consumers in the nearby parishes to a meeting to discuss the issue, which then might appoint a committee to investigate the subject more closely. The committee might investigate the interest of the inhabitants of these parishes in electrification and the costs of a transmission and distribution system. The committee or its technical consultant would then contact the town utility for terms of delivery.

While the initiative thus might stem from the hinterland consumers, it was of course still the single urban municipal council that had the power of decision. Some municipal councils refused to supply their hinterland. For instance, the negotiations between the technical committee of the Odense municipal council and neighbouring rural municipalities around 1910 broke down, as the latter could neither present sufficient guarantees for a 'suitable electricity demand in a number of years', nor for a monopoly for the Odense utility. The majority in the Odense municipal council then decided that the maximum prices demanded by the rural municipalities would imply a larger risk than the 'proper attention of the municipal economic interests' could justify.[79] Likewise, the municipal council of the Zealand town Ringsted rejected a contract with a co-operative society formed by hinterland consumers, despite support from a majority in the council's electricity committee.[80]

As the considerable diffusion of town-based district systems illustrates, however, many municipal councils indeed did agree to supply the hinterland. In these cases, the main argument was not necessarily that supply should be profitable, as it was in the pioneering case of Fåborg mentioned above. In fact, even the Fåborg utility continued to expand its high voltage network into the hinterland in order to supply 'its entire natural supply area' despite large costs and criticism; One critic called this expansion an 'economic nail in the municipal coffin.'[81] And in the above case of Fredericia, the chairman of the electricity committee of the municipal council argued from the beginning of the decision process in 1913 that electrification of the hinterland would not be a financially lucrative project. When he recommended the project to the city council, he pointed at another basic concern for the municipality: Supply of the hinterland would help tie the hinterland to the town. This concern did not justify hinterland supply if this would result in a deficit, but made it acceptable if the income matched the expenses.[82] In Fredericia, as in other cases, the electricity committee therefor concretely demanded from the consumer representatives a minimum electricity consumption, which would guarantee a return on investment. The general procedure to achieve this guarantee was to collect non-binding subscriptions by potential consumers to estimate the electricity demand in the parishes to be electrified, which then served as a basis for negotiations between the electricity committee of the town council and the representatives of the rural consumers. In the case of Fredericia, the agricultural society of Fredericia and sorroundings organized agitation meetings in the different parishes and managed to raise non-binding subscriptions for more than seven thousand electric lamps and fourteen hundred horsepowers motorpower. On this basis, the municipal council of Fredericia univocally accepted to continue the project, provided that a binding subscription gave a similar result. As this binding subscription proved even higher than the previous non-binding one, the council took a loan of four hundred thousand DKK to build the system, which at its inaguration in 1913 included twenty-eight transformer stations. Notably, to improve the economy of supply, the utility also included large power consumers as the municipal water works and a local weaving mill. After two years of operation of the hinterland supply system, its economy proved more than acceptable: The transformer stations with low voltage distribution networks had yielded a return on investment varying from nine to sixty-seven percent, with an average of twenty percent per transformer station.[83]

The co-operation between municipal producers and hinterland consumers

The organisational form for hinterland supply, however, might differ from utility to utility, as it included negotiation between the municipal utility and the hinterland consumers. There were at least four models of organisation; in each case, the system contained the same physical elements, but these might be owned, financed and/or managed by different actors.

First, the municipal company could - like in the cases of Fåborg and Fredericia above - build, own and exploit the entire system and thus provide electricity to the individual consumers. This model was used by about half of the thirty-one utilities exploiting a town-based system in 1923.[84] To guarantee a return on investment, the utility might demand a guarantee from the individual consumers on a minimum annual electricity consumption. An extreme example is the municipal utility of the large Jutland town of Randers, which exploited one of the largest town-based district systems in the provinces (the large system in North-Eastern Jutland in figure 3.2), supplying consumers in forty-five rural municipalities at its inaguration in 1915. In the negotiations, the consumers insisted on a model, in which the municipal utility owned and managed the entire system; they were guaranteed a fixed electricity price, and did not have to participate financially. In return, however, the individual consumer was not only obliged to purchase all his electricity from the utility for twenty-five years, but also to use no other source of lighting than electric lighting or candles. If not, the consumer would still have to pay the utility an annual fee of 2.5 DKK per installed lamp connection. Likewise, power consumers obliged themselves only to increase their motor power for threshing, grinding etc. with electric motors and not with steam engines, petrol engines or windmills. Consumer representatives later tried to change these harsh conditions, but the changing municipal councils could not reach agreement on the issue at least until the 1930s.[85]

A second model was that the town utility supplied electricity to local associations of consumers at the local transformer station. These so-called 'transformer societies', organized as co-operative societies, might finance and own their local low voltage distribution networks and sometimes all or part of their transformer station. In the contract between the municipal utility of the Northern Jutland town Brønderslev and six transformer societies (1921), for instance, it was specified that the municipal utility would own the high voltage transmission network in the hinterland as well as the transformers, but that the transformer societies would own their low voltage distribution networks. In 1923, six town-based systems held such contracts with transformer societies; the largest of them was the municipal supply company of Odense, which supplied some sixty-three transformer societies in the hinterland through sixty-seven transformers. A decade later it supplied no less than hundred and twenty transformer societies.[86]

In a third model, all consumers in the hinterland might organize in one large co-operative society, which built and operated its own transmission network. The 'transmission company' would purchase the electricity from a municipal utility at the town border, and then transport it on its own transmission and distribution system to the consumers. Alternatively, like the transmission company supplying the hinterland of the Northern Jutland town Nørresundby, it might supply local transformer societies, which in turn supplied the individual consumers. The rationale for the establishment of such consumer owned transmission companies was a certain degree of independence from town based utilities. The large transmission company in the hinterland of Århus and Randers [*Århus Randers Kaløvigegnens Elektricitets-forsyning*, ARKE], which became operational in 1917, is illustrative. The argument to establish a transmission company exploiting its own transmission system was to maintain independence from particularly the municipal utility of Randers, which as mentioned above put up harsh demands to the individual consumer. After consultance with a leading promotor of co-operative utilities, engineer Bjerre from the D.V.E.S. company in Askov, and after satisfying results from subscription lists circulated in the area, the consumers established their co-operative society in 1915 with the standard objective 'to supply electricity to the area as cheaply as possible.' After studying various possibilities, it was decided to purchase electricity from the municipal utility of Århus. The latter established a convertor at its power station to produce alternating current at six kilovolts, which was supplied to the city border. Here, ARKE established its main transformer station, increasing the tension to fifteen kilovolts for transmission over its large supply area. Already at its inaguration in 1917 the Århus-based district system had one of the largest transmission networks in the country, with a maximum reach of more than fifty kilometres, and including more than ninety transformer stations (with a capacity of nearly 4 MVA).[87]

In 1923, this model was followed by four systems; in a fifth case, concerning supply of the hinterland of Ålborg, the established co-operative society of Himmerland could not decide to build its grid after many years of discussion and preparation. The society dissolved itself in the early 1920s, and instead the Ålborg municipal company, its consulting engineer and a Danish cable works established a limited company (1922) to build the transmission system and supply the interested consumers of the area. This company would on one hand purchase electricity at the municipal border, and at the other end supply local transformer societies.[88]

Finally, a fourth model of co-operation was the establishment of a partnership by the municipality and the co-operative society of hinterland consumers to own and exploit the means of production. In the cases of the islands of Langeland and Morsø, for instance, co-operative societies of rural consumers was established just after the First World War. Their original purpose was to purchase power from the urban municipal utilities of Rudkøbing and Nykøbing Mors respectively, and then act as transmission companies. However, in both cases their consulting engineer - P. A. Petersen - worked out a scheme, in which the municipality and the transmission company established a partnership to take over the power station and the transmission system, after these had been expanded and build by the respective parties. The partnership then supplied electricity to the partners at production costs, which then supplied the town and the hinterland respectively. In terms of ownership, the municipality owned one third and the rural consumers two-thirds; in the executive board, however, the power relations were reversed.[89]

Such a partnership arrangement was made in six cases (including the co-operative society in Odder). Incidentally, in two of these cases - the partnerships based in Esbjerg and in Kolding - the transmission company contributed to the partnership with a small hydropower plant, which was run in parallel with the thermal power station situated in the town. These arrangements appeared in the wake of the fuel shortages of the First World War, and due to their rather local character such co-operations are not considered as centralized systems in this dissertation (see also the next chapter).

The diffusion of rural district systems

As in the case of rural local systems decribed in the previous chapter, and that of rural transmission and distribution systems described in the previous section, the actors exploiting rural district systems were associations of consumers. Also the overall objective for establishing district supply was similar: Following the widespread agitation for electrifying agriculture, electricity should be made available to rural consumers. While town-based district systems as a rule were expansions of already existing local systems, rural district systems were thus build as new systems and provided electricity to most of their consumers for the first time. As it was put in the agitation for gathering subscribers for the South-Eastern Zealand district system, which went through several phases before it was realized, this form of organisation "was necessary to raise the capital, or else there would be no electricity."[90] Or, as it was put retrospectively in the case of the small Mid-Jutland district system [*Midtjyllands Elektricitetsforsynings Selskab*, MES], operational in

1922, the point was that electrification with local systems in few villages and autoproduction installations on few larger farms left many places unelectrified; but if consumers jointly established a larger scale system, the entire district could benefit, as 'agriculture as a whole can't continue to lack electrical power.'[91]

Initiatives and decisions

The establishment of rural district systems in many ways resembled that of rural local systems and particular that of rural transmission systems. The actors were largely the same, that is, persons or organisations concerned with the economic development of the area: Influential local individuals, agricultural organizations or representatives of local government. In case of the MES utility, the initiative stemmed from the local innkeeper, who was locally known for his initatives with regard to public life. And in the cases of the other small Jutland systems based in Brande (operational in 1910), Hovedgaard (operational in 1911) and Vestbirk (operational in 1923), the issue was raised by a local member of Parliament. In Brande, for instance, the local MP, who took the initiative together with the local parish official, had been inspired partly by the diffusion of electricity supply in towns, and partly by the use of high voltage transmission to supply distant customers by the Tuborg-Klampenborg electric traction company. Then he decided to investigate the possibility to provide hydro electricity from a nearby river to the village of Brande and the farmers in its surroundings.[92] Alternatively, the initiative might stem from local consumer associations, which each planned a local system, but now decided to join forces in a common system. In the case of the rural district utility of Falster (*Falster Højspændingsværk*, operational in 1912), for instance, two electricity commissions preparing a local system in neighbouring parishes experienced a huge interest from potential consumers, and then decided to erect a joint district system instead of two local systems.[93] Finally, in some cases the issue was raised by outsiders like consulting engineers, as in the cases of reinitiating the district supply schemes for North-Western Zealand and South-Eastern Zealand. As described above, however, this happened in close negotiation with representatives of the consumers.

With regard to the actual decision process, also in this case the initiators would gathered a group of potential consumers, which then appointed a committee to investigate the matter further, and prepare a technical and financial feasible basis for the project. Then they called a founding meeting for the company, mostly as a co-operative society. The general meeting then had the final power of decision, but authorized an executive committee to negotiate and carry through the actual technical, financial and organisational construction process. Corresponding to the scale of the supply scheme, the committee often consisted of representatives of the consumers from the different districts involved - for instance organized by parish or by transformer station.

Again, the case of the small MES utility is representative.[94] Firstly, a committee consisting of influential men from different rural municipalities in the district did the preparations. For instance, they hired technical and organisational expertise in the form of the large Århus consultancy firm Eriksen & Sardemann, which assessed the technical and economical feasibility of the project. Simultaneously, they investigated the possibilities for raising capital by contacting different banks, and arranged agitation meetings throughout the district, where interested consumers could sign on non-binding subscription lists. Once they had a solid demand and a technical, organisational and financial plan, they called for a founding general meeting establishing the co-operative society MES, which was attended by some two hundred people. Here the plan was presented fully to the meeting: Power would be produced in a small hydro-power plant; contrary to the neighbouring hydro-powered system of Brande, which had served as an inspiration, the company should purchase an existing hydro power station from a heather flour mill, which was idle after demand for heather flour decreased after the First World War. In addition, on non-binding subscription lists consumers had signed for twenty-two transformer stations. The project would cost eight hundred thousand DKK, while annual expenses were about eighty-six thousand DKK. As a result, electricity could be supplied at a kilowatt-hour price of price of seventy øre to locally formed transformer societies, which was a competitive price in the years just after the First World War, which had greatly increased material and fuel prices.

The general meeting of consumers then voted on the continuation of the project: With a majority of 139 against 86, it allowed a 'building committee', consisting of representatives from each transformer society, to carry out the project, provided the costs would not be exceeded by more than twenty-five percent. This committee then negotiated with the owners of the flour factory on the price of the hydropower station and invited offers from electrotechnical firms on the electrical machinery, wires and installations. Also, it agitated and gathered binding subscriptions from consumers. Finally and not the least important, it sought and obtained a loan at the municipal credit association, and obtained guarantees for this loan from the rural municipalities in the district. All larger decisions were formally taken at the general meeting. When the system was operational in 1922, it had cost a million crownes, and light was sold for sixty-three øre, power for thirty-three øre per kilowatt-hour. In the following years the system grew steadily, and had over sixty transformer stations by 1946 (figure 4.4).

Alternative options

Which, then, were the arguments to establish district supply instead of the alternative supply options, such as supply by several local systems or by purchasing electricity from elsewhere, possibly including the exploitation of a transmission and distribution system? As in the case of the MES utility, a first argument not to establish local systems was that this would leave much of the district unelectrified. Another argument was pointed out in the case of the South-Eastern Zealand system, where engineer Frederik Krebs negotiated with several parish electricity committees preparing local systems in order to interest them for a large common district supply system. An important argument for the latter to postpone their local supply schemes, and consider the possibility of common district supply instead, was that local supply might prove to be an expensive deroute, if a common system would be established anyhow in the future. The unnecessary expenses of the deroute could be saved if district supply was feasible. Krebs was then given the oportunity to collect non-binding subscriptions and work out a finance plan. When the scheme indeed seemed feasible (Krebs raised subscriptions for 12.000 lamps and 1250 hp. engine power), it was decided to go for the common system.[95]

The other option was to establish a transmission company and purchase electricity from elsewhere; such transmission companies could negotiate with different producing utilities, and thus find the cheapest supplier. Also with regard to the actually established rural district systems, the executive committees in charge might investigate this possibility, at least if there was a larger system nearby and purchase thus was feasible. For instance, in the case of the small Vestbirk hydro power system in the hinterland of Horsens, a co-operative society was established to exploit a transmission and distribution system in 1921; negotiations on supply from the Horsens municipal utility failed, however, as the latter did not have sufficient surplus capacity. The executive committee also investigated purchase from the Odder and Gudenaa utilities, but finally decided to build and exploit a new hydro power station. At a general meeting, the committee was authorised to proceed, provided the costs would hold.[96] Another case is again the South-Eastern Zealand system, the executive committee of which negotiated extensively with their Northern neighbour NESA on purchase of steam power electricity and, if NESA's plans to import Swedish hydropower were successful, to purchase cheap hydropower. NESA offered to build the long ten kilovolts transmission line between the two systems, against a large fee and a guarantee for a minimum purchase by the new utility. The advantage for the latter would be that it saved the investment in a new power station. Still, the executive committee was in doubt if there would by an economic advantage. Another possibility was merely to purchase nightly current, when the load was very low, but in this case SEAS should build the transmission line. Also this arrangement, however, was found economically unattractive. Finally, the excutive committee had severe doubts about the reliability of such a long high voltage connection, which still represented new and unpreceded technology in Denmark. Although NESA was positive on this reliability, the committee decided to build its own power station.[97]

Rural electrification in Denmark

Prior to the introduction and diffusion of centralized electricity supply particularly in the 1920s, then, rural Denmark had been electrified first by a large number of village utilities operating small local systems, then by a number of municipal utilities expanding their district systems into the hinterland, and finally by a number of rural district utilities establishing their own rural district systems. However, there was a significant difference in the pattern of rural electrification between Western Denmark (primarily the main land of Jutland and the island of Funen) and Eastern Denmark (primarily the large islands of Zealand, Falster and Lolland), separated by the Great Belt (table 4.2).

Table 4.2: Rural electricity supply by type of supply system in Eastern and Western Denmark in 1923/24[98]

	Eastern Denmark			Western Denmark			Total		
	Systems	Trafo-stations	Sale (GWh)	Systems	Trafo-stations	Sale (GWh)	Systems	Trafo-stations	Sale (GWh)
Town-based district & centralized systems	2	48	1	23	950	14	25	998	15
Rural district & central-ized systems	4	808	22	11	473	4	15	1281	26
Local village systems	65	-	4	293	-	10	358	-	14
Total	71	856	27	327	1423	28	398	2279	55

On one hand, the table shows a much larger number of systems in Western Denmark than in Eastern Denmark - both town-based systems, large scale rural systems and local village systems. The West-Danish region thus primarily contributed to the large diffusion of decentral electricity supply systems in terms of numbers. And on the other hand, it shows that this followed the dominance of different actors on the supply field: In Eastern Denmark, rural electricity supply was dominated by four large rural district utilities of Northern Zealand (NESA), of South-Eastern Zealand (SEAS), of North-Western Zealand (NVE) and of Falster (FH), which accounted for about eighty percent of the rural electricity sales in the region through more than eight hundred transformer stations. In addition there were sixty-five village utilities (excluding small town utilities), which accounted for some 14% of the rural electricity sales, while the role of municipal utilities in rural electricity supply was marginal. In Western Denmark, by contrast, rural electricity supply was dominated by town utilities, which supplied about half of the electricity through about a thousand transformers, and nearly three hundred village utilities, which supplied about a third of the electricity. Finally, only a sixth of the electricity was supplied by few rural district utilities (including the new Gudenaa partnership on the Mid-Jutland centralized system, which will be addressed in detail in the next chapter).

The different supply structure in these two regions partly reflects different natural and social geographical features, which the actors anticipated. For instance, it was a natural geographic precondition that Western Denmark was significantly larger than Eastern Denmark, although it was equal in terms of population. As a result, few expansive district utilities in Eastern Denmark rapidly covered nearly the entire region: By the early 1920s, the transmission systems of the Northern Zealand (reach: 50 kilometres), North-Western Zealand (44 kms), South-Eastern Zealand (42 kms) and Falster (25 kms) utilities had reached common borders, and left only badly covered areas within their own supply areas and the island of Lolland open to the expansion of other systems. In Western Denmark, however, there remained plenty of space uncovered for large and small utilities to expand, which made the competition between different utilities much less. This was so despite the presence of a number of large systems expanding in the countryside, which compared to the large East Danish systems: In 1921, ten West Danish systems had a reach of more than twenty-five kilometres, including those based in Århus (78 kms) and Esbjerg (61 kms) and that of the Gudenaa partnership (60 kms).[99]

In addition, it was a natural-geographic precondition that the few and relatively small attractive Danish hydropower resources were situated in Western Denmark. Rural actors repeatedly chose to exploit such hydropower systems as a district supply system; in fact, out of the ten rural district systems in Western Denmark in 1923, no less than six derived all or part of their electricity from hydropower turbines, while also the Gudenaa partnership exploited a hydro powered system.

And finally, it was a social geographic precondition that despite the roughly similar number of inhabitants, there were simply more large towns in Western

Denmark than in Eastern Denmark, which had the capacity and the will to expand into the hinterland - either by themselves or with consumer participation. Besides the twin towns of the Danish capital area, which did not engage in rural electricity supply, the nine largest Danish towns were situated in Western Denmark. In all of these, the municipal utility expanded supply to the hinterland. Moreover, in lack of fierce competition for the rural consumers that existed in Eastern Denmark, West-Danish municipal utilities in general were more likely to adopt district supply: By 1923 nearly 50% of all West-Danish market towns had established a town-based district system. But in Eastern Denmark, merely 20% of all market towns had established one. In fact this were only six towns; the utilities in the other market towns were not interested in supplying their hinterland, which already was covered by the large district utilities. Instead, they often purchased additional electricity from these district utilities.[100] And even the town utilities that adopted district supply might only use it to supply large consumers within the town, and not expand beyond municipal borders.[101]

The most noteworthy feature of the diffusion process of district supply, perhaps, is its rather decentral character; while local supply naturally had a decentral character because of the limited transport distance of low voltage distribution systems, district supply entailed the possibility to cover large areas from a single large power station. However, in Denmark attempts to create new actors to exploit truly large scale systems mostly failed, and most district systems were established by the traditional and rather decentral actor of the individual urban municipality, particularly in Western Denmark. In addition, particularly in Eastern Denmark there were a number of fairly large rural district systems, but these did not manage to include the provincial towns in their supply. And also in the case of rural district systems there were a number of smaller systems, particularly those established to exploit relatively small hydropower resources.

5

Centralized systems until the Second World War

Developments in Germany

From the First World War, the new configuration of centralized electricity supply appeared abroad and in Denmark. This configuration is characterized on one hand by the interconnection of larger power stations of previously independent electricity supply systems in a power grid of very high voltage. And on the other hand, the production of electricity is further concentrated in relatively few but large power stations, which provide the base load of the entire system. During the First World War, the further concentration of electricity production in such a large supply system was put on the agenda in circles of progressive electrotech nical engineers and of governments in a number of European nation states, including Germany, Austria, Norway, Sweden, Switzerland, Great Britain, the Netherlands and also Denmark. Particularly developments in Germany had an exemplary function for Danish engineers. Here the centralized supply option was fiercely debated, particularly after a series of papers by Georg Klingenberg, the director of the large electrotechnical manufacturer *Allgemeine Elektrizitäts Gesellschafft* and professor at the polytechnical school in Berlin. Klingenberg suggested to establish such centralized supply systems at the level of the German States through intervention by the state governments.[1] While a controversy arose on the questions of ownership and organisation, a consensus arose on the technological shape of the new type of electricity supply: In Klingenberg's view, the production of electricity was to be concentrated in very large thermal power stations, that is, power stations with a capacity of eighty to one hundred megawatts. Within the single power station, electricity production should be concentrated in few large turbogenerators, perhaps with a capacity of twenty megawatts each. Such power stations should be build near mine mouths, where fuel was available at particularly low costs. If hydropower was available, large hydropower stations should also be included in the scheme. In addition, such large power stations should be interconnected with power lines of very high capacity, that is, operating at perhaps a hundred kilovolts and with a transport capacity of twenty to forty megawatts. Besides interconnecting the different power plants, the power grid should also supply the largest load centres directly. By 1917 such centralized supply schemes were discussed in several German States such as Sachsen, Baden, Bayern, Preussen and Würtemberg.

Klingenberg's motive for the introduction of this new configuration of electricity supply was economical. First, the concentration of production would decrease the costs of electricity production per unit of output, both because of the situation of power plants where cheap fuel was available and due to economies of scale. Second, the power grid not only served to transport such particularly cheap electricity to the consumes; it facilitated intensive co-operation between the participating power stations, which for instance gave a reduction in investment costs in back-up units for emergency or maintenance situations. For instead of each investing in full back-up capacity, the participating power stations could share back-up capacity through the power grid and thereby reduce the total amount of back-up units in the system. And third, also the load of the entire area could be shared by the power stations on the grid: Load managers would be able to allocate the production of the needed electricity at a given time to production units anywhere in the system. Thus they could select the cheapest production units, but also run only the amount of units necessary to supply a given demand at a given time, and thus avoid overproduction of electricity. Without a grid, each power station in the area would have to run its large turbogenerators even if demand was low, and thereby produce surplus electricity which could not be sold.

Introducing the concept of centralized supply in Denmark

In Denmark, the German discussion was followed by leading electrotechnical engineers, for whom German developments generally functioned as a primary frame of reference for developments on their field. The issue was for instance raised by Kay Emun Rager, the later journal editor and Member of Parliament but currently an engineer at the NESA utility, in an address to the Electrotechnical Society on the 'co-operation between power stations' in January 1917. Rager in detail referred the designed supply scheme for the German State of Sachsen, in which the production of electricity would be concentrated primarily in two very large and interconnected thermal power stations, while four or five of the largest and most modern existing power station also were included. The point of this supply scheme was to achieve a significant decrease in electricity prices. According to Rager, such a scheme of centralized supply would be equally advantageous in Denmark; on one hand it would facilitate the electrification of still unelectrified areas, while on the other hand it would imply a rationalization of the existing electricity supply structure.[2]

Also other Danish engineers discussed Klingenberg's ideas, the progress made in Germany and the relevance for the Danish electrification process.[3] Most influential, without doubt, was an address by NESA's director, Aage Angelo, to the Danish Society of Engineers later in 1917. The address, titled 'the centralisation of electricity supply', irreversibly put the issue on the technological agenda. While he eschewed conclusions on the organisational side of the matter, Angelo's address focused upon the principles for the future development of electricity supply in the direction of centralized supply in Denmark and the motive for establishing such a supply configuration. The address was published in separate print for wider distribution, and his arguments became a central reference point for discussions on centralized electricity supply for at least a decade.

With regard to the motive for introducing centralized supply in Denmark, Angelo took a national-economic perspective, which since dominated discussions on electricity supply in Denmark. He contended that the current electricity supply structure evidently implied great national-economic losses compared to a more 'rational' supply structure. In the absence of a 'guiding force', the electricity supply field had developed into a multitude of mostly small power stations. Only few of these qualified as 'large' power stations: In terms of production, approximately half of the annual public electricity demand was produced by two large power stations in the Capital area, leaving a true multitude of power stations to produce the other half. This uneconomical production in small systems 'cost the country several hundreds of thousands of krones annually, which could have been saved if the electricity supply had been guided in another direction.'[4]

Moreover, Angelo expected a fast increase in electricity demand in the near future of more than a three-fold over the next ten to fifteen years. It was this increase that made the question of a rational electricity supply structure imperative: While the existing situation was a matter of fact, similar short-sightedness in the future could still be avoided. Notably, also this 'black-boxing' of the electricity demand would be typical in later arguments favouring centralized supply; while the rapidly increasing electricity demand was treated as an autonomous variable, which could be anticipated by constructing a rational electricity supply structure, it was of course not a completely independent variable in fact; besides the complex dynamics of the consumer market, the utilities themselves made an increasing effort to stimulate electricity consumption and thereby improved their economic performance due to scale and load advantages.

With regard to the more 'rational' configuration of future electricity supply, Angelo did not present a concrete design, but merely formulated the guiding principles. His key argument was that electricity production in Denmark should be concentrated in the largest possible power stations. To support this proposition, he compared the economic performance of some hypothetical systems representing different scales of electricity supply, a line of argument which also would become a standard element of the discourse on centralized supply. Concretely, Angelo compared the economic performance of the power stations of three electricity supply systems differing in size, power source and load (table 5.1): (1) a village power plant, characterized by a small (thirty kilowatts) diesel generator, a small agricultural load and a small annual production and sale; (2) a district power plant, characterized by a larger generating capacity (three 500 kW diesel generators), a small but more varied load, and a larger annual production and sale; and (3) a truly large power plant, characterized by a much larger steam generator capacity (three 5 MW turbogenerators), a large and varied load, and a large production and sale. Unsurprisingly, Angelo's presentation showed clear economies of scale: Compared to the annual costs of the largest plant, the annual fixed (interest & repayment) and running costs (wages, fuel, maintenance etc.) per unit of electricity sold were twice as high for a district plant, and more than six times as high for the village power plant.

Table 5.1: Production costs in three electricity supply systems according to Angelo (1917)

	Annual sales (GWh)	Investment costs (DKK)	Annual costs					
			Fixed costs*		Running costs		Total	
			(DKK)	pr. kWh sold (øre)	(DKK)	pr. kWh sold (øre)	(DKK)	pr. kWh sold (øre)
Local village power plant	0.017	35.000	2.450	**14.5**	2.750	**16**	5.200	**30.5**
District system power plant	1.5	750.000	52.500	**3.5**	100.000	**6.5**	152.500	**10**
Very large power plant	22.5	4.000.000	280.000	**1.25**	790.000	**3.5**	1.070.000	**4.75**

*Annual interest and repayment are set to 7% of the investment sum.

Angelo's conclusion, therefore, was unambiguous: In the future, the production of electricity ought to be concentrated in as few and as large power stations as possible. Under no circumstances should more village power plants be established. Similarly, district power plants (corresponding in characteristics and economy to existing plants in Danish provincial towns) would gain from receiving electricity from a larger plant instead of producing it decentrally. In addition, the existing village plants should be replaced by transformer or conversion stations under a larger system; the gains in production costs would more than compensate for necessary investments in new alternating current distribution networks, transformers and interconnections. Small rural district plants could with a relatively low investment be connected to larger systems, as they already used alternating current. Finally, also town district plants should transfer their production gradually to larger power plants, but could be maintained as back-up capacity.

Angelo thus focused upon economies of scale, and saw the establishment of a power grid primarily as a means to transport cheaply produced electricity to load centres. The main technical challenge, therefore, was to increase the reliability of high voltage lines and standardize the transmission voltages, so that smaller district systems could be interconnected in a larger centralized system. He only briefly mentioned other advantages of interconnections, such as common load management; he did not 'prove' this advantage in the way he 'proved' the economies of scale, but merely repeated the idea that the overall economical performance of all power stations in the system could be optimized by adapting the number of active power stations to the required electricity demand at a given time of the day.[5]

Visions of centralized electricity supply on a national scale

During the 1920s, agitators for centralized supply further developed this rhetoric. Moreover, they made their vision concrete through a presentation of several schemes of centralized supply systems covering the entire country. Such designs were first presented in the context of private organizations such as the Danish Society of Engineers and the new association of Danish utilities [*Danske Elektricitetsværkers Forening*, D.E.F.] established in 1923. And when the national government was interested in the issue in the late 1920s, also a government committee was set to investigate the arguments for centralized supply and propose a national centralized supply scheme.

Faber's 1921 design

A first design of a centralized supply system at a national scale was presented in 1921 by Svend Aage Faber, the former director of the Tuborg-Klampenborg electric traction company (now NESA) and currently a consulting engineer engaged in a number of large scale electricity supply projects. After introducing his ideas in electrotechnical journals, Faber presented his vision in an address to the Danish Society of Engineers, which like Angelo's address four years earlier appeared on separate print for wider distribution. Faber motivated the necessity of a centralized system covering the entire country in those earlier papers. The immediate incentive for designing the scheme was the possible connection between Norway and Denmark, possibly via Sweden, in order to import Norwegian hydropower in Denmark. This possibility was currently negotiated in a commission with government representatives from the involved countries. The full exploitation of such a connection would demand a large enough supply area, which in turn demanded a power grid with a high transport capacity covering all of Denmark. Still, Faber argued, even if the import project failed (in fact it wasn't realised until the 1960s[6]) the scheme would be of major interest: For under all circumstances a grid would in time be necessary, partly to connect the different centres of production and consumption, partly to facilitate exploitation of indigenous power sources at times this was technically possible and economically advantageous, and partly to facilitate the concentration of production 'in few, large power stations to achieve optimal economy both in investments and running costs.'[7] This economic savings following the concentration of production would compensate for the costs of a power grid.[8]

With regard to the technical scheme, it first included a nation-wide primary power grid with a high transport capacity, and which interconnected the producers of electricity and the larger load centres in the country (figure 5.1).[9] With regard to these load centres, the grid was to supply primary transformer stations, from where the electricity was further transported: The East-Danish grid should supply such primary transformer stations in the gravity points of the existing large rural district systems, and at a junction near the provincial town of Roskilde. In Western Denmark, the grid was to supply primary transformer stations at the main provincial towns by means of a North-South interconnection supplying the towns in Eastern Jutland (Aalborg - Randers - Aarhus - Horsens - Vejle - Fredericia - Kolding -Aabenraa) and an East-West interconnection including Odense on Funen and Esbjerg in Western Jutland. In addition it included an already existing interconnection between the provincial towns Århus and Skive, built in 1920 (see below). The operation voltage of the grid was to be fifty kilovolts; from the primary transformer stations, the electricity could be further transported to the consumers by a secondary network of medium high voltage (10-15 kV) and a distribution network of low voltage (380/220 V).[10] In time, an increased load could be met by building a new power grid for a hundred kilovolts or more in order to feed the fifty kilovolts grid at selected points.

With regard to supply of electricity to the grid, the scheme first included interconnections with foreign electricity supply systems to facilitate the import of hydropower. At the Western end, it included the possible future connection between Northern Jutland and Norway, possibly via Sweden. At the Eastern end, it included the already existing connection between Northern Zealand to Sweden (see below). Second, it included the concentration of electricity production within Denmark in few large thermal power plants strategically situated on the grid. Notably, also if the large scale hydropower import plans succeeded, these were necessary to provide full thermal back-up capacity. At the Eastern end of the grid, the large and recently inaugurated H. C. Ørsted power station in Copenhagen could be enrolled, possibly assisted by NESA's power station slightly North of Copenhagen. At the Western end, a new power station could be built near Ålborg in Northern Jutland. And finally, in the gravity point of the system the favourably situated power station of a large autoproducer, an electric wire and cable company [*Nordisk Kabel- og Traad-fabrikker*] in Middelfart on Funen, could be taken over by the exploiters of the grid. Finally, as a third source of electricity the grid should interconnect with existing or future power stations, that could exploit indigenous energy resources in Jutland. Several hydropower plants were near some East Jutland towns, and thereby already within the reach of the system. Moreover, the scheme included two primary transformer stations near large peat bogs North and South of Ålborg respectively. And finally, a Western Jutland trajectory passed the hydropower resources at Tange, Holstebro, and near Varde as well as lignite deposits near Ringkøbing.

Faber was praised by his peers for his initiative; however, the concrete design was severely criticized, particularly because of the lack of extensive and careful calculation of the options. As Frederik Krebs put it, Faber's scheme 'perhaps looked good, but ten other schemes might do as well or even better.'[11] Particularly the future electricity demand was a crucial variable in this respect. Faber, in reply, stressed the importance of the scheme as a vision: He maintained that the future demand could not be predicted more than a year or two ahead with an acceptable margin of error, and that the point of discussing a national supply system was to determine a general strategy to meet the future electricity demand, when the existing mode of electricity supply became unsatisfactory - which it would sooner or later.[12]

The only design characteristic, that was discussed in detail, was the operation voltage of fifty kilovolts. It was suggested repeatedly that this voltage was far to low to achieve sufficient transport capacity. Faber defended his choice by emphasising that fifty kilovolts was currently the maximum tension for power transmission by submarine cable and for a cheap type of mast isolators, while it was also a standard voltage abroad - which meant quick and cheap supply of materials. And most important, this transport voltage would be sufficient for the purposes of the system, which was not to transport electricity over very long distances, but to transport it from the strategically placed feeding points to the nearest load centres.[13]

A guideline for individual interconnections: The 1926 design

A second grid design was presented in the context of another private interest organisation, the association of Danish utilities DEF. Inspired by its German counterpart [the *Vereinigung der Elektricitätswerke*], the association was established in 1923 to investigate technical and commercial issues following the diffusion of electricity in society, as well as represent the utilities towards the State.[14] Again, the initiative to study the issue of centralized supply stemmed from Faber. It was after his address on the issue of co-operation between individual utilities, that the association appointed a committee to investigate these matters more closely in 1924. Faber himself was appointed its chairman.[15] When this committee presented its work at the annual meeting of the association in 1926, it correspondingly concentrated upon the character, economy and organisation of individual cases of co-operation from the point of view of individual utilities. This included such issues as the connection of transmission networks versus direct interconnection of power stations, and its consequences for back-up capacity, parallel operation of power stations and reliability of the system; the sharing investment expenses; common management; and so on. But the committee also addressed the need for a national grid in its final remarks: For the construction of interconnections between two co-operating utilities should occur according to one grand scheme, so that each individual interconnection 'in time might become a natural part of one coherent system of high tension lines for achieving the largest possible economy and reliability.'[16]

The committee thus presented such a grand scheme, which only included a grid and not its power supply (figure 5.2). The relevant variables of the design were the standard voltage level and of the grid trajectory. In both aspects the grid resembled Faber's earlier design: Interconnections should again be designed for fifty kilovolts, and the trajectory deviated only marginally by including some additional interconnections (notably two connections between Eastern and Western Denmark), and by lacking the now stranded project of interconnecting West Denmark to Norwegian hydropower.

When the need for such a national grid was discussed at the next annual meeting of the association, the principal ideas of the grid were again not questioned. But the lack of argumentation in the form of economic calculation for this form of supply was again a crucial issue: In want of exact figures, the representatives from middle sized and smaller utilities would not accept the economic necessity of a national grid for a matter of fact.[17]

The national-economic gains of centralized supply: The 1929 design

This weakness, however, was amply addressed in the first study on the issue by a government committee. In 1928 the Minister of Public Works, Johannes Stensballe, appointed the 'committee for future guidelines for the economical procuration and distribution of electricity.' An engineer himself and chairman of the Society of Danish Engineers, Stensballe had participated in the 1927 annual meeting of the association of Danish utilities, where Faber had defended the need for an national power grid design.[18] Now, 'urged by several parties', he appointed the committee to investigate how 'a more economical arrangement of electricity supply in the country could be achieved.' In its first report of 1929, the committee translated this mission into 'a quantitative investigation to the question of large scale co-operation between existing power stations in the country would yield direct economic advantages.'[19] Faber was again heavily involved; besides inspiring the minister to appoint the committee in the first place, he was a committee member and its technical secretary, and - most important - the chairman of the technical subcommittee, which designed a new national electricity supply scheme and performed the calculations on its economical advantages.

The report was really a sophisticated argument for the national economic gains of centralized electricity supply. The technical subcommittee narrowed down the investigation to a quantitative comparison of the electricity supply expenses of two scenarios: In the first scenario, there was no co-operation at all, and local and district systems co-existed in complete isolation. In the second scenario, the utilities co-operated rationally. This 'rational co-operation' was defined as the interconnection of power stations, which facilitated the concentration of electricity production either in few large power stations, or in power stations exploiting indigenous energy resources.[20] In the case of electricity production from indigenous power resources, national-economic savings followed a reduction in fuel imports; the feasibility of such production depended upon the size of investments, fuel market prices and transmission distances. This advantage was clear and not further included in the investigation. Likewise, imports were not included in the co-operation scheme.

The resulting centralized supply scheme was characterized by both similarities and differences with the earlier designs (figure 5.3). Important similarities include the Eastern Jutland interconnection from Aabenraa in the South to Aalborg in the North, with a branch to Odense on Funen. Also most of the Eastern Denmark grid was similar, as it in fact had been build in the mean time. An important difference, however, was that the design operated with two unconnected centralized supply systems instead of one national system: It consisted of an East-Danish grid operated at fifty kilovolts, and a West-Danish grid operated at sixty kilovolts.[21] The latter also interconnects some smaller power stations in Northern Jutland at twenty kilovolts and on Funen at thirty kilovolts. The low priority of an interconnection of East and West Denmark followed co-operation with foreign partners: Eastern Denmark would co-operate with the centralized system of Southern Sweden by fifty kilovolts, while Western Denmark would co-operate with the centralized system of Northern Germany, which used sixty kilovolts. As each system thus had its foreign partner, the expensive submarine interconnection over the Great Belt would only be necessary if solid fuel prices rose so high, that Swedish hydropower had to be made available also in Western Denmark.

With regard to production of electricity, the base load was to be carried by large power stations situated near the ends of the grid and near the largest load centres. The East-Danish grid was to be supplied by power stations in Copenhagen, Nakskov and possibly Kalundborg (power station not on the map). The West- Danish grid was to be supplied by power stations at its Northern, Southern and Eastern ends in Ålborg, Åbenrå and Odense, as well as a power station near its largest load centre in Aarhus. The largest power stations in Århus and Copenhagen should be in operation continuously, while the other main power stations should be operated so as to achieve optimal system economy. The many smaller, already existing power stations on the grid, mainly diesel powered stations in provincial towns, were to be used for back-up or peak capacity only.

In order to compare the economy of this centralized supply scheme with an alternative scheme of isolated power stations, the committee also developed a scenario for electricity supply without co-operation, which had to 'undo' the existing co-operation on for instance Zealand and in Mid-Jutland. In this scheme, all provincial towns had their own supply systems, while rural areas were mainly supplied by rural district power stations in Eastern Denmark and by municipal town power stations in West Denmark. Together, this scheme included twenty-eight power stations in East Denmark and twenty-nine power stations in Western Denmark. Village power stations were not included.

The economy of the two schemes was then calculated in detail, and showed that the annual expenses of electricity supply were lower for the centralization scheme. The subcommittee included roughly the same variables as Angelo more than ten years earlier, but also made a substantial effort to quantify them. With regard to investment costs, centralized supply would of course imply extra costs following the construction of a grid - that is, high capacity power lines, transformer stations and conversion stations. In return, there would be important savings with regard to the central expansion of production capacity. Few large power stations could expand the production capacity with larger production units, which were cheaper pr. kilowatt capacity, whereas many small and independent power stations had to expand with many smaller (and thus relatively more expensive) units. For instance, in a steam power station a sixteen megawatts expansion would cost 230 DKK pr. kilowatt, while a four megawatts expansion would cost 300 DKK/kW and a two megawatts expansion 350 DKK/kW. In addition, due to the sharing of back-up capacity on the grid, co-operating power stations needed to install significantly less back-up machinery than the independent power stations: For example, in one scenario it calculated with a total backup capacity in the centralized supply scheme of 25 % of the maximum load (or 20% of the production capacity), compared to a back-up capacity of independent systems of 50% of the maximum load (or 33% of the production capacity). With regard to running expenses, finally, there would also be scale advantages in a scheme of centralized supply: These would on one hand be due to the larger thermal efficiency of large units, which operated with higher steam pressures and used economizers. And on the other hand, maintenance and operation could be centralized causing a decrease in wages.

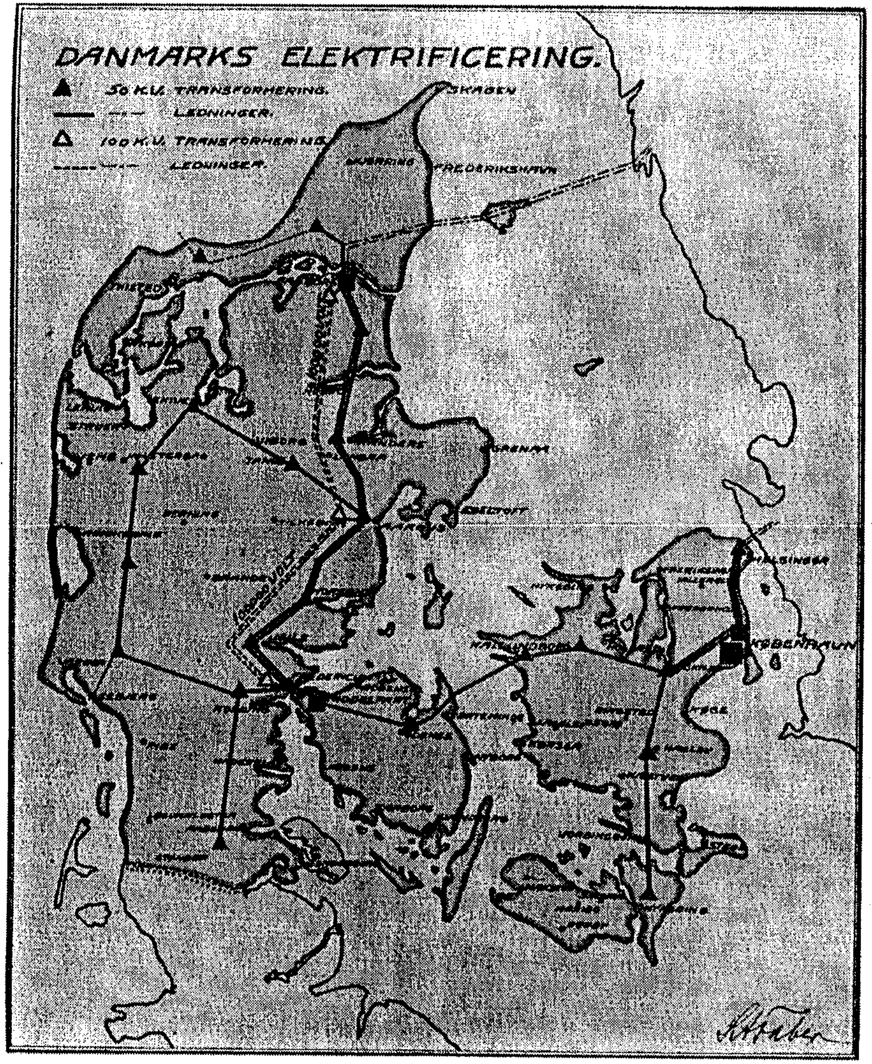


Figure 5.1: Svend Aage Faber's vision of a centralized electricity supply system, which covers entire Denmark and is connected to the Swedish system. Legend: ■ = Power station; ▲ = Primary transformer station; — = 50 kV power grid. Source: Faber 1921c.

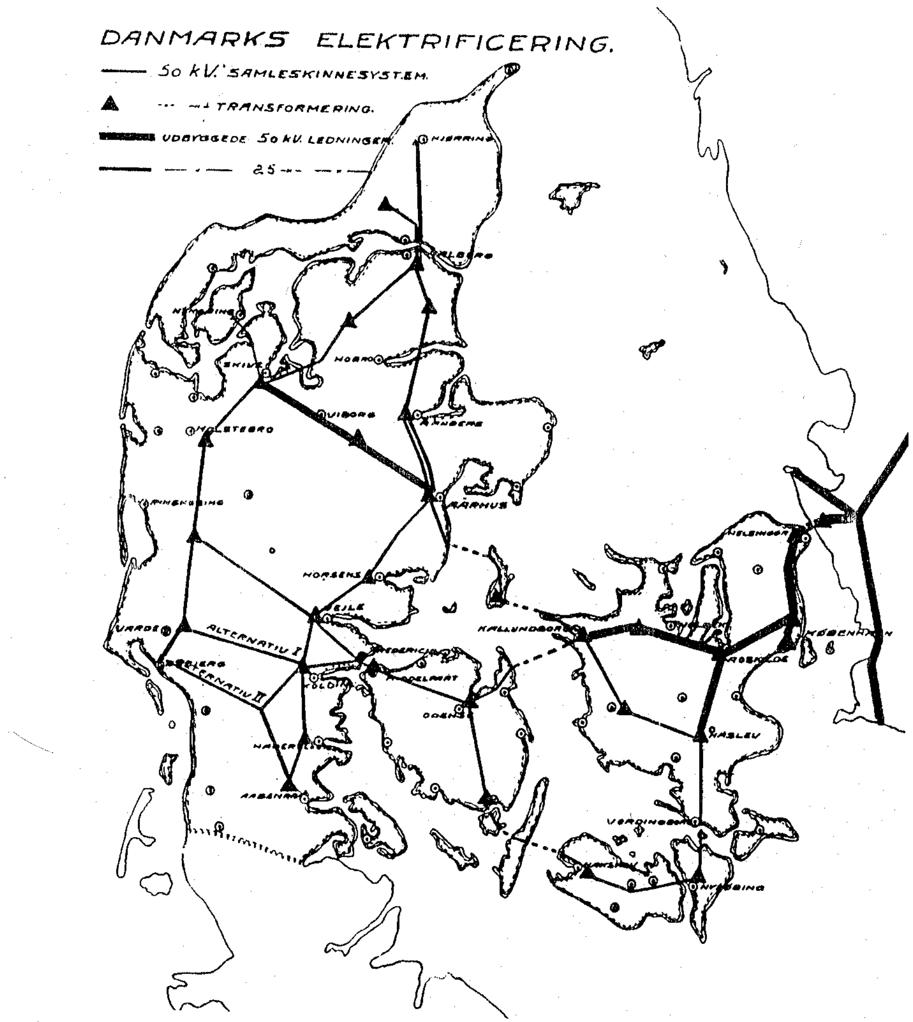


Figure 5.2: Sketch of a power grid covering entire Denmark, consisting of primary power lines and transformer stations, as presented by the a committee under DEF in 1926. The thick lines represent already existing power lines. Source Faber et. al. 1926.

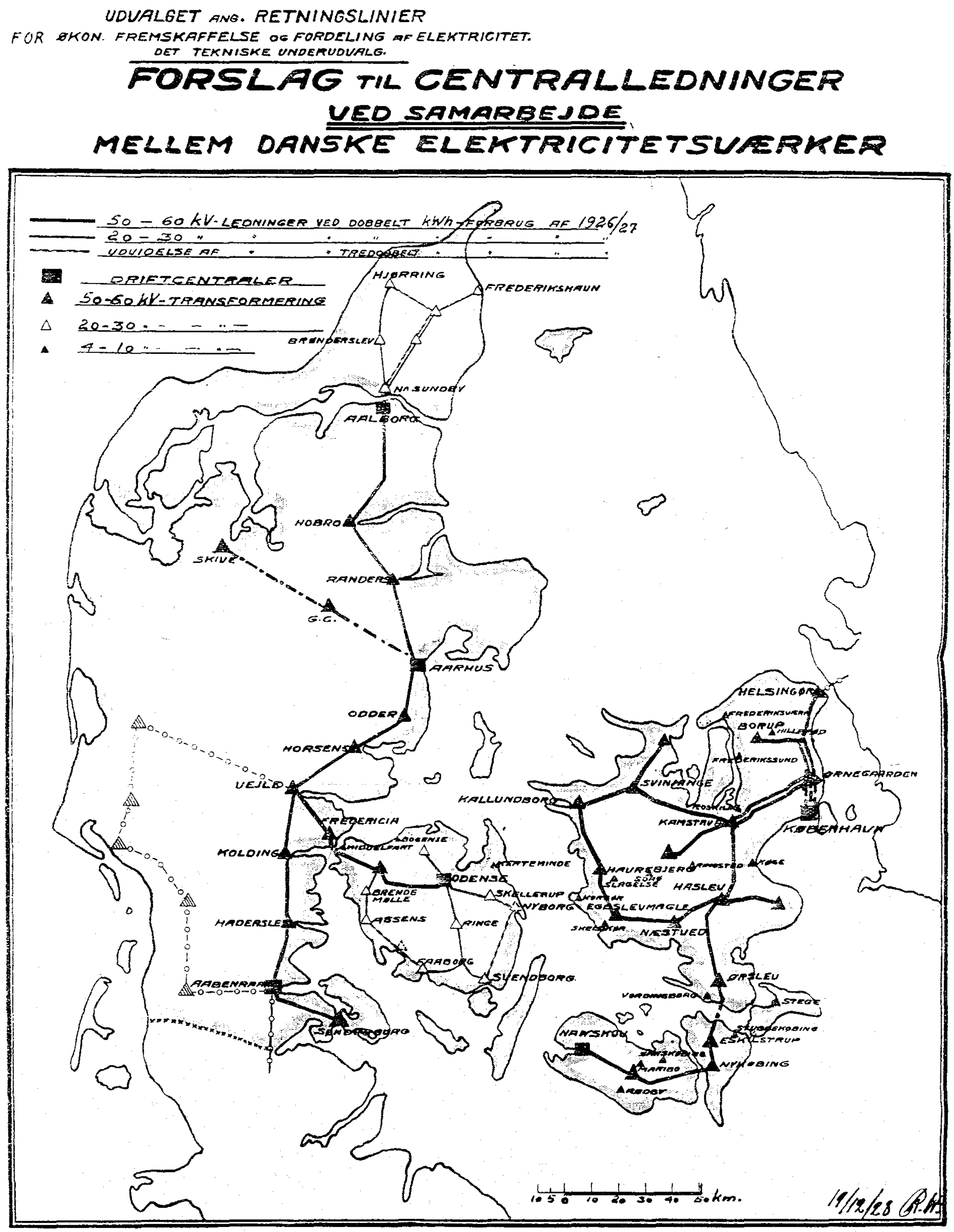


Figure 5.3: The centralized supply design presented by a committee under the Ministry of Public Works in 1929. Legend: ■ = Main power station; ▲ = primary transformer station; — = Primary power grid. Source: Betænkning (1. del) afgivet af udvalget ... (1929), Appendix A, 2.

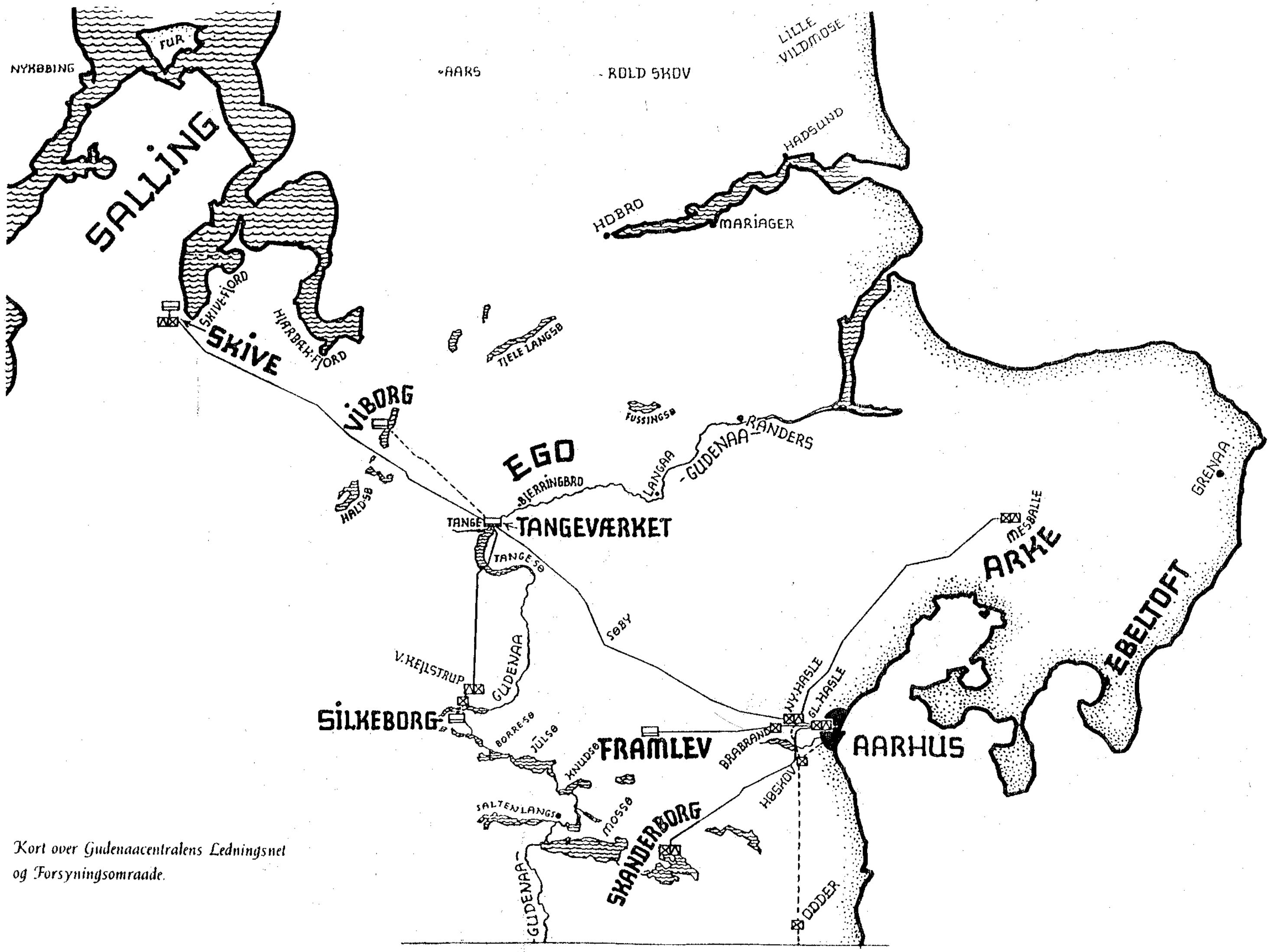


Figure 5.4: The Mid-Jutland co-operation. From the 1920s, the hydropower plant at Tange and the thermal power plant in Århus pooled their power on a fifty kilovolts interconnection, jointly supplying all or additional electricity to other utilities in the region, a number of which still had their own small power stations. Source: Ellert 1943, 77.

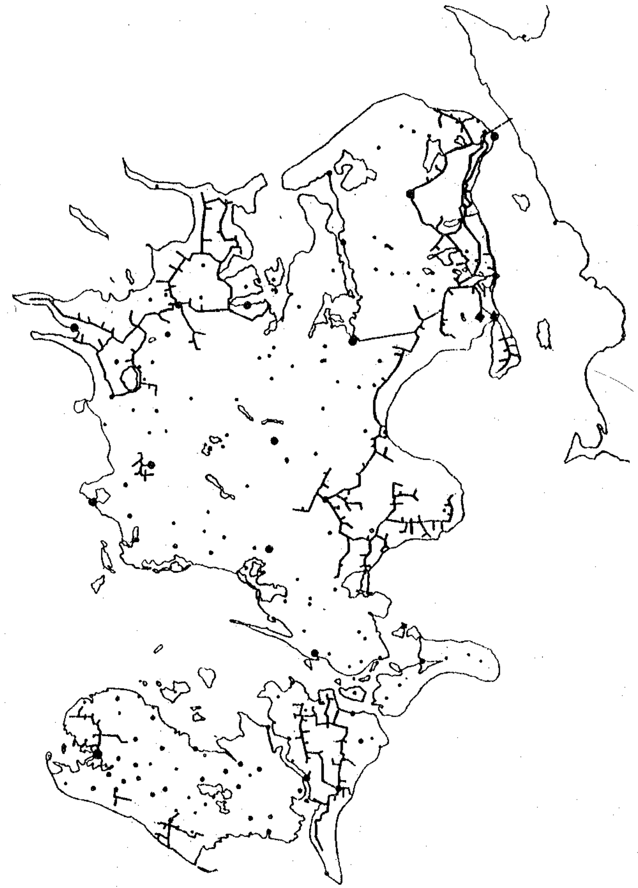


Figure 5.5: High voltage lines in Eastern Denmark in Januari 1920. The 10 kV transmission grids of NESA, SEAS and the utilities in the capital (6 kV) had been connected, while those of NVE (in the North-West) and also FH (on the island of Falster) remained isolated. Source: Elektroteknikeren Vol. 16 (1920), appendix.

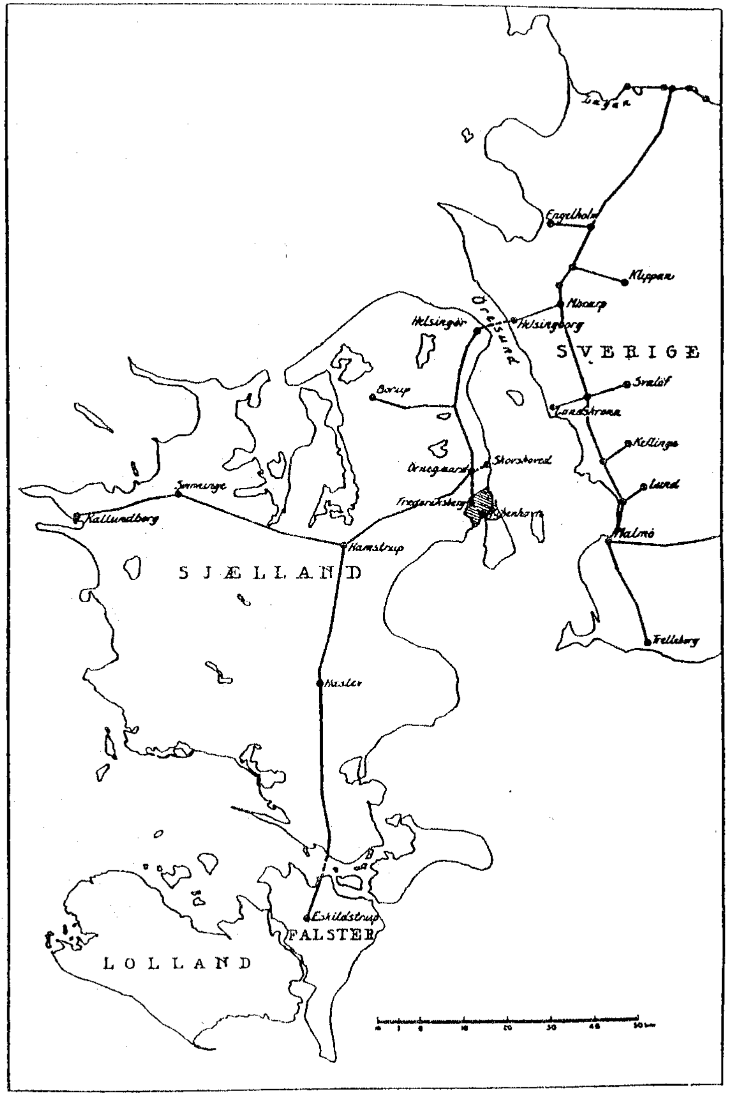


Figure 5.6: The East Danish 50 kV grid by 1928. Source: Nordsjællands Elektricitets og Sporvejs Aktieselskab ... 1927, 87.

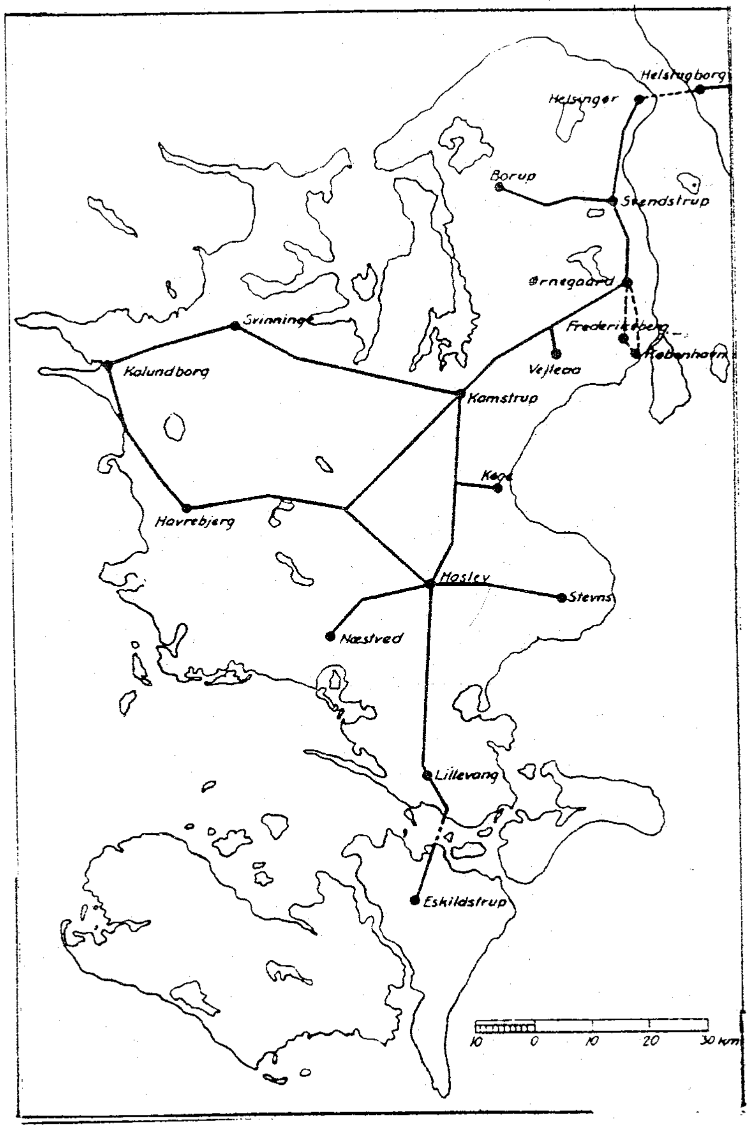


Figure 5.7: The East Danish centralized supply system in 1937. Source: Sydøstsjællands Elektricitets Aktieselskab 1912 - 19. December - 1937 (1937), 79.

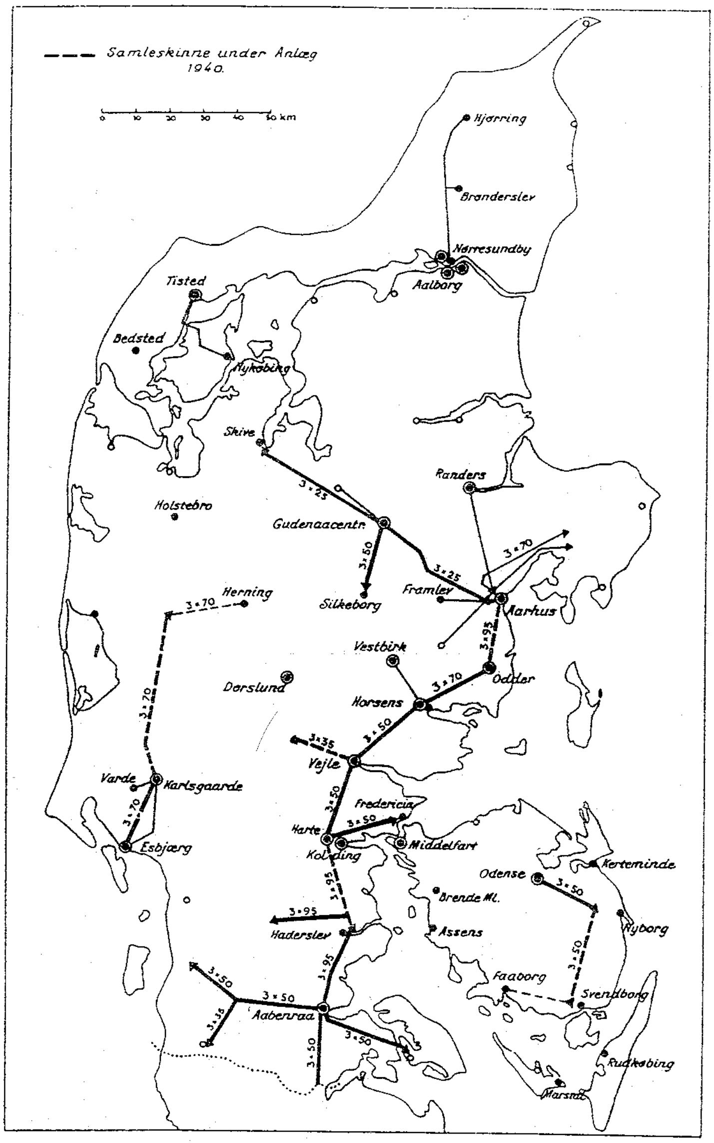


Figure 5.8: Existing and planned power lines with a voltage higher than twenty kilovolts in Western Denmark in 1940. Source: Appendix to Bramnæs et. al. 1940.

In the case of a three-fold of the electricity production relative to the year 1926/27, and the back-up capacities mentioned above, the annual expenses were twenty-four percent lower for the centralized supply scheme than for the non-co-operation scheme. On the basis on this work of the technical subcommittee, the government committee strongly advised the Minister to stimulate the establishment of centralized supply on a national scale.[22]

Hydropower and the first developments towards centralized supply

By then, centralized electricity supply had already been introduced on a more modest scale for about a decade. The first two Danish systems, which can reasonably be characterized as centralized supply systems, had been established in the late 1910s and the early 1920s. In both cases, a co-operation was developed which involved the pooling of power from large plants with different characteristics, that is, power produced in thermal and in hydro power plants. And in both cases this co-operation occurred on actual interconnections, that is, separate high voltage power lines operating at a significantly higher voltage than the customary ten kilovolts used in the transmission networks of many district systems. It is in these aspects, that the first centralized systems differed from earlier 'local' co-operations between for instance thermal power stations in towns and small hydropower stations in the immediate vicinity.

NESA and Swedish hydropower

The first Danish electric utility to participate in an interconnection of different power plants on a separate grid was again the progressive Northern Zealand district utility NESA. Like it had early on embarked on district supply under Faber's leadership, it now worked towards a centralized supply system under Angelo's direction, starting by the establishment of an interconnection to Swedish hydropower plants in 1915.[23] Its partner in this co-operation was the production company Sydsvenska Kraftaktiebolaget in Southern Sweden. This company had been established in 1906 to exploit the available hydropower resources in the region, and had five Swedish urban municipalities as its main shareholders. By 1909, it operated four hydropower stations with a total production capacity of some twenty megawatts.

The Swedish company had already considered the possibility of electricity exports to Denmark when it was founded, but although Faber had designed a preliminary project for such transmission of hydropower under the Sound, the project had not been realized. However, NESA resumed negotiations in 1912, now with Angelo as its director and Faber as its vice-president. As the Swedish hydropower plants at certain times of the day and of the year had a large excess of hydropower, which the Southern Swedish towns could not consume, the Swedish company was prepared to sell this electricity to NESA for a particularly low price. NESA thus gained access to cheap but irregular supply of hydro electricity. Organisationally, NESA gained a forty year concession on the import of Swedish hydropower. The Danish utility also financed and built most of the transmission system, including a submarine cable under the Sound entering the Danish coast at Helsingør, the distance of which from the Swedish coast was only about five kilometres. Operational in 1915, the cable was operated at twenty-five kilovolts, then the maximum voltage for submarine cables, and had a transport capacity of some six megawatts.

When this cable had proven its reliability, NESA built the remaining trajectory of the system - a power line of some thirty kilometres from Helsingør down to its central transformer station 'Ørnegaarden' in Lyngby, North of Copenhagen. Operational in 1918, this was the first fifty kilovolts transport line in Denmark. In the same year, NESA decided to build a new and larger thermal power plant next its old plant at the coast just North of Copenhagen, likewise with a capacity of six megawatts. When this power station was operational in 1920, the company had the largest steam power capacity in Denmark after the two municipal utilities in the capital, and could pool this thermal power with the hydropower imports from Sweden: Imported hydropower was used whenever available, and the thermal units produced the rest. Notably, until the late 1920s the co-operation with the Swedish utility remained limited to transport in one direction - from Sweden to Denmark. From then NESA would incidentally export electricity to its Swedish partner, an arrangement which first gained structural importance in the late 1950s.

The Mid-Jutland co-operation

A second large scale project involving an interconnection of primary power plants was established in the other end of the country, in Eastern and Mid-Jutland, and involved Denmark's only larger hydropower plant.[24] The hydropower plant was established in 1920 in Tange at the Gudenaa river, Denmark's largest river although small in an international perspective.[25] The hydro power plant was built to exploit the maximum potential of some five megawatts, which is also small in an international perspective, but at the time qualified as the largest power plant in the region. Notably, this hydropower plant was in a first instance to function in a large district system, which should supply most of the Mid-Jutland region including factories, countryside and towns. If these - like the large town of Århus - already had an electricity supply system, the hydropower system would provide additional electricity. Only in a second stage the system would function as a centralized system, in which the output of the hydropower plant and the large thermal power plant in Århus were pooled for joint supply of the region.

Notably, both Faber and Angelo were also involved in this project. Faber had been engaged by a committee studying the possible exploitation of the Gudenaa river as its consultant in 1909, which resulted in a report describing the possibilities of supplying the region with hydro electricity.[26] Moreover, while the urban municipalities in the region did not show much interest in the project, Faber and Angelo were among the applicants of a concession for the exploitation of the hydropower resources to the Ministry of Public Works at the beginning of the First World War, and thereby revived the project. Yet when the municipalities in the region did gain interest in the project as a result of the increasing fuel prices, they withdrew their concession application to the advantage of the latter. In return, they were engaged as consulting engineers.

After several years of negotiation, in 1918 several urban municipalities and rural district utilities - some with and some without a thermal power station of their own - founded the production partnership *Gudenaacentralen* to build and operate the system. By then, a number of utilities and municipalities (among which Randers, Grenaa, Viborg, Silkeborg and Hobro were the largest) had chosen not to participate; they criticised the proposed scheme for an underestimation of the costs and the lacking possibility to later extend the hydro power capacity. The project was saved, however, as the large Århus municipality purchased their shares, and thus become the largest shareholder. This move was motivated within the municipal council by the possibility to postpone an expensive extension of its own thermal power station by purchasing additional hydro electricity. Besides Århus, three smaller municipalities (Skive, Skanderborg and Ebeltoft), a small rural district utility (Framlev) and three rural transmission companies (ARKE, Salling and EGO) participated from the beginning. In the 1920s, also the municipality of Silkeborg joined the partnership, while the municipal supply company of Viborg was interconnected (before finally joining the partnership in 1941). Technically, the partnership established an artificial lake and the hydropower station at Tange, as well as part of the transmission system. The latter included a main transmission line Århus - Tange - Skive of eighty-six kilometres, operated at fifty kilovolts. The other partners were connected by transmission lines of smaller capacity, operated at ten or fifteen kilovolts (figure 5.4).

The rapid development of this district supply system into a centralized supply system had been anticipated from the beginning: Already the 1910 study, Faber and his collaborator proposed that when demand would exceed the hydropower capacity, electricity could be provided through the 'combined operation' of the hydro power station and the Århus thermal power station.[27] When the system was under construction, Faber persuaded the partnership to build the main transmission line for fifty kilovolts instead of the planned twenty-five kilovolts exactly in order to facilitate future transport of thermal power in the system.[28] Indeed, the hydropower station proved too small to meet the rapidly growing electricity demand already few years after its inauguration in 1921, and several smaller partners negotiated contracts with the municipal utility of Århus on supply of additional thermal energy through the transmission network of the *Gudenaacentralen* partnership. Particularly after the establishment of a new large power plant (with a capacity of sixteen megawatts) in 1928, the Århus municipality could easily fill out this role. Thus a practical co-operation developed, in which the hydropower station would always run at its maximum, while the Århus plant provided additional electricity to interested partners. The co-operation was arranged in individual contracts between the different utilities, however, until a reorganization in 1939 allowed the partnership to negotiate with Århus on behalf of all partners and became the centre for the production, purchase and supply of electricity.[29]

The actors of centralized supply: The State as a non-actor

These two centralized systems covered only a fraction of the country. But in the interwar period, the diffusion of centralized supply made steady progress, in particular in Eastern Denmark. By the beginning of the Second World War, most of this region had been covered by a centralized supply system. In West Denmark, by contrast, there existed only two centralized systems, which were mutually unconnected, and covered only a modest part of the region. First during the 1950s centralized supply was extended to the entire country and replaced the more decentral forms of electricity supply.

Who, then, were the actors behind the diffusion of centralized supply? Indeed, the question of who should build and operate centralized supply systems had been an important issue in engineering and later also in government circles. For technically the establishment of a centralized supply system at a national scope was not particularly problematic; the basic elements needed to build such a system, such as high voltage power lines and large production units, had been developed and tested abroad. As one observer put it as early as 1917, 'were the money available, the engineers could start building the day after they obtained the relevant data.'[30]

Concretely, the question was if new actors should enter the electricity supply field. It was broadly agreed that the initiative should not be left solely in the hands of the existing actors, the utilities, for it was them who had been responsible for the current dispersion of Danish electricity production in many small units.[31] Small utilities often lacked the incentive to give up decentral production; this might be due to ideological frictions between municipal and rural systems, in which the latter insisted upon their self reliance. Moreover, rural utilities might depended on 'less capable and less conscientious consultants', who found a market in constructing and maintaining expensive decentral systems without regard to the developments in the field of electrotechnology.[32] Municipal utilities, by contrast, might have sufficient knowledge and resources to pick capable consultants, but here the municipal exploitation of electricity supply as a source of income might be an obstacle. Finally, it was incidentally acknowledged that small systems might simply be economically feasible as they were situated in favourable load environments. For the larger system to be feasible, however, it would have to include these lucrative environments too. In sum, a new central and powerful actor was needed to favour general interests over local interests.

An obvious candidate for intervention was the national government, which both possessed the financial means to meet the huge investment costs of centralized systems, and the legislative means to enforce central control with the development of the electricity supply business. Moreover, Danish engineers knew that state intervention was being discussed abroad from the very beginning, when centralized supply was put on the agenda. In Germany, during the First World War professor Klingenberg had pleaded for State ownership of the means of production and the grid, as only the State could overcome the problems with interconnection.[33] In practice, different governments of the German States planned to participate in the construction of centralized systems, either by monopolizing the electricity supply business, or by establishing joint companies with some large utilities.[34] In Great Britain the discussion was on the intervention of the national government, which resulted in a 1926 Electricity Supply Act appointing a State power board to build and operate a national power grid, and to select a number of power stations fit to supply it. In 1947 the electricity supply business was nationalized, when the State also took over the operation of public power stations. Likewise, in France a 1922 Electricity Supply Act authorized the state to organize and lead a co-operation between utilities to build and operate a power grid. If utilities were unwilling to comply with a national centralized supply scheme, it had the competence to take over their power stations. In 1946, a state company was erected by law to carry out production, transmission and distribution of electricity in the entire country (yet without a monopoly). Finally, in hydropower countries as Finland, Sweden and Switzerland the State directly participated in the establishment and exploitation of large scale centralized supply systems, establishing state-owned companies to make state-owned hydropower resources productive.[35]

Lacking state participation and the initiatives of technical societies

In Denmark, however, until the late 1920s the strong measure of State interference was eschewed both among the progressive engineers and by the different national governments.[36] With regard to the latter, these followed a role defined in collaboration with representatives of interest organisations during the preparation of the first Electricity Supply Act of 1907: To stimulate the 'free development of electricity supply' by supportive measures, but not hampering such development by actual interference.[37] Such supportive measures included safety regulations and the possibility to expropriate ground for the establishment of electricity supply systems. In addition, in exceptional cases it had yielded financial support to construction projects. The largest subsidy was given to the construction of the large district system of Southern Jutland, after this 'electrically backward' area had been regained from Germany in 1920 following the result of a referendum, as specified in the treaty of Versailles. Other examples of financial support, likewise following the First World War, concerned projects developing hydropower resources in Denmark, provided they were interconnected with other power stations and provided local employment. Finally, in some cases the national authorities discussed the matter of electricity supply as the establishment of concrete systems demanded approval; this included the first centralized supply systems, which involved approval to import Swedish hydropower (which was granted in return for an annual fee to the State and a guarantee that sufficient production capacity would be available on Danish ground) and the concession on exploitation of the Gudenaa river (granted on the condition that all interested utilities could participate).

With regard to the engineers advocating centralized supply, the case for State intervention was occasionally made. Following Angelo's address to the Danish Society of Engineers in 1917, for instance, one participant suggested a that the State should establish 'an institution, which should judge all projects, and constrain the realisation of those projects, which do not fit into the projected scheme.'[38] And when presenting his national supply scheme at the same society in 1921, Faber went a step further: Frustrated by problems in current negotiations between different utilities on co-operation, in which he participated, he proposed to eliminate the problem of co-operation by establishing one State company to build and operate the grid and the primary power stations.[39] However, for the time being these proposals were rejected in the discussions. Summing up the results of the first discussion, the chairman of the society of engineers interpreted the common point of view to be that the State should not interfere with the free development in the electricity supply business; the utilities needed 'authoritative guidance' rather than 'forced development', which could be provided by the electrotechnical expertise. And with regard to the 1921 discussion, Faber's suggestion was forcefully countered. For instance, Kay Emun Rager (now employed in the electrotechnical industry and editor of an electrotechnical journal) argued that the interests of the engineering community and those of the State collided: First, because civil servants were not known as the greatest supporters of rapid initiative and taking the necessary risks, and because the State would probably would tax electricity supply to increase its income, State participation would slow down the diffusion of electricity in society. And second, the State tended to appoint 'some jurists' rather than engineers in leading administrative positions, even in State companies operating on technical fields.[40]

The solution preferred in engineering circles to stimulate centralized supply in the late 1910s and most of the 1920s, then, was to establish a form of guidance for voluntary participation from the side of the utilities. This strategy resulted in two concrete initiatives. A first initiative followed directly after the discussion at the Danish Society of Engineers in 1917.[41] The society appointed a committee, often called 'centralisation committee', to seek the support of important actors such as county and municipal governments, which could in turn influence the decisions in individual utilities either directly or through their policy of granting loans. Moreover, it sought close co-operation to the Electricity Commission, the State institution established by the 1907 electricity supply act to handle matters of expropriation and safety. As all electric utilities (and autoproducers) were to obtain permission for expansion projects with regard to safety, the Electricity Commission was in a position to influence decisions on decentral expansion. Notably, a co-operation between the centralisation committee and the Electricity Commission was eased, as three members of the centralization committee - NESA director Angelo, professor Rung and principal T. F. Krarup - also were members of the Electricity Comission, the latter as its chairman. Concretely, this co-operation for instance resulted in an address to all county authorities, announcing that the Electricity Commission would gladly judge the economic feasibility of expansion projects proposed by utilities seeking county loans. The address also enclosed special prints of Angelo's 1917 talk for distribution to all members of the county councils.[42] Likewise, in municipal decision processes, municipal council members might suddenly find Angelo's talk on their tables.

While this close co-operation between the agitation committee and the supposedly neutral State commission at first seemed to strengthen the cause, however, is soon proved to be compromizing. This aspect was problematized by the consulting engineer Peder Anders Pedersen, whose consultancy firm worked for (decentral) municipal utilities. In this capacity, Pedersen was surprised by the sudden interference of the Electricity Commission with local policy matters, which he interpreted as a pressure to give up local expansion of production capacity. He pointed out to the municipalities involved that the notion of centralized supply was not an ideal accepted by all engineers, but rather an ideology of a small group of engineers. Moreover, these often had a direct business interest in a concentration of production: Director Angelo's large utility, for instance, would sell more electricity in such an arrangement, and Angelo and Rung had direct financial interests in the expansion of the Gudenaa river system. Such interests did not harmonize with their role in the Electricity Commission or the centralization committee under the Society of Engineers, which both acted as neutral institutions while seeking to convince municipalities to give up local production and connect larger systems instead.[43]

Pedersen's critique ended in a court of arbitration of the Society of Engineers, in which he sought to provoke an evaluation of the competence of the Electricity Commission. However, in agreement with the Minister of Public Works, the chairman of the latter manoeuvred the institution out of the reach of the court of arbitration by denying its competence. The case was then reduced to a personal dispute between Pedersen on one hand and Angelo and Rung and the other.[44] Angelo was cleared, as the chairman of the Electricity Commission Krarup promised that Angelo had never participated in decisions, in which he had a personal interest. Professor Rung, to his fury, was severely criticized for using his status in private business matters.[45] A more important result of the court case, however, was that the credibility of so-called 'impartial' expert institutions as the Electricity Commission and the centralization committee had been publicly compromised, and the initiative of the society of engineers obstructed.

A second attempt to guide developments in the direction of centralized supply was made by the Danish association of utilities. Being a forum also for the decentral utilities themselves, the association sought to create some consensus among its members. It is important to note, however, that in the early years of the association many utilities did not join: Most important, the large majority of municipal utilities did not join the new association until the association of municipal utilities collectively joined the Danish association of utilities in 1927. Another large group, the village utilities, remained unrepresented until the 1930s.[46]

Nevertheless, when it presented the national supply scheme described above, the committee on co-operation under the association also proposed to pass a resolution, stating that the members of the association should act in accordance with the master scheme, which was of vital importance for the Danish electrification process.[47] The vote on this resolution was postponed, however, and when the issue was taken up at the association's next annual meeting in 1927, the resolution had been severely criticised in the forum for the municipal utilities (see chapter seven). Although the municipal utilities joined the national association in 1927, then, it was clear that there would be no consensus: At the 1927 annual meeting, it was observed that the scheme was 'music for the future', as many decentral actors were not interested. Another suggestion was to establish a committee to advise the members on expansion projects, and the members indeed did authorize the executive council to establish such a committee.[48] Such measures were not taken, however; instead, leading propagators of centralized supply would co-operate with the new government committee, and in this way seek to influence developments.

The 1935 Electricity Supply Act

From the late 1920s, however, the passive role of the state was under revision. As mentioned above, the lack of national-economic rationality in Danish electricity supply was put on the political agenda through the establishment of a government committee under the Ministry of Public Works; this committee not only presented a national supply scheme and an argument for the economic superiority of this type of electricity supply, but also urged the State to intervene in the public supply business in a second report published in 1933. The authors, including Faber and Rung, did neither suggest direct State participation in the construction process, nor its introduction of a concession system to enhance central control of the business. These were found too strong measures: For instance, the concession system 'with its accompanying detailed rules regarding prices, account keeping, management etc.' was 'probably alien in this country and should therefore be avoided.'[49] Instead, they advised the Minister to establish 'a less interfering way' of guidance by extending the competence of the Electricity Commission from approval of expansion plans on technical grounds to approval on economical grounds too, that is, the Electricity Commission should judge if these projects would 'constrain for a longer time the establishment of the desired co-operation'. If so, it should have the competence to deny approval.[50]

The report was followed up by a Bill and resulted in the new Electricity Supply Act of 1935. But taking account of opposition formulated by the municipal utilities (see chapter seven), the Minister moderated the Bill: The Electricity Commission would indeed be replaced by an Electricity Council with a wider competence, in that utilities were obliged to apply both for approval of construction projects on ground of safety and on economical aspects. Yet the Electricity Council would not get the competence to deny approval of construction projects on economic grounds in cases, which involved already existing systems not exceeding their natural supply areas, nor involved in co-operation with other systems. Notably, this modification concerned the means, not the aim of the 1933 report: As professor Rung put it in a presentation of the Bill, its objective remained that 'most of the small power stations should die a slow death.'[51] The Minister hoped that the authority of the Electricity Council would convince utilities to give up decentral expansion of production capacity, and seek connection to a larger system voluntarily. If not, the competence of the

Electricity Council should be increased in a revision of the Act after five years.[52]

These ideas were largely accepted in the two chambers of Parliament, and with some amendments resulted in the Electricity Supply Act of 1935.[53] In the final Act, the Electricity Council was given the competence to deny projects concerning interconnections, if these obstructed the construction of existing or future power grids. In such cases, the utilities could only appeal the decision to the Minister of Public Works. But with regard to projects concerning the expansion of production capacity, regardless if it was to be used in a co-operation or not, the verdict of the Council had only advisory status. If utilities chose to ignore a negative advice of the Council, the latter should write a report (a so-called declaration) motivating its position, which should be made public; but it could not stop the project.

The main issue of Parliamentary debate, then, concerned not the competence of the Council but its constitution. To ensure that its power was not abused, the different interests should be represented among its members. Besides members with specific electrotechnical and legislative competence, the Council should include representatives of the utilities of the capital, the municipal utilities, and the rural district utilities, while it also included representatives of the electricians and of the different consumer organisations such as the Industrial Council [*Industrirådet*], the agricultural council [*Landbrugsrådet*] and the association of parish councils [*De samvirkende Sognerådsforeninger*]. Furthermore, the council would take the point of view of individual utilities in its economic assessments of the different supply options: Instead of evaluating projects according to their national-economic, long term feasibility, it would calculate short-term economic gains for the single utility. It would only recommend centralization, then, if it could prove economic benefits for all parties involved.[54]

When the Act was due to revision in 1940, the decentral electricity supply structure had not changed at all; however, the chairman of the Electricity Council, professor Albert Krogh Aubeck did not desire an extension of its legal competence. In a 'free democratic country' as Denmark, he described the very thought of using force as 'repellent', and trusted that reason would prevail voluntarily in the long run.[55] Instead, centralization could be stimulated by improving the communication between the Council and the decentral utilities and by providing cheap loans for the construction of (inter)connections.[56] As neither the associations of utilities desired an increase of the competence of the Council, and the politicians echoed Aubeck's argument, the only change of importance in the Act was the formal inclusion of a representative of the village utilities in the Council.[57]

The Second World War

Finally, neither the crisis situation of the Second World War caused the State to change the legal framework of electricity supply in order to carry through a rationalization. This was so despite the fact that a committee under the Prime Minister's Department, which had investigating the fuel supply situation, suggested in 1940 that a national electrification scheme should be designed and that 'the authority of the Electricity Council should be increased from a advisory to a compelling one.'[58] But the committee appointed to investigate and carry though such a change (the so-called 'Electricity Commission of 1941') never managed to meet during the war at all, and after the Liberation it was dissolved, with the exception of a technical subcommittee designing a centralized supply scheme for Western Denmark (see chapter nine).[59]

The acute shortages of fuel supply, however, did cause the State to interfere temporarily in another way. Following a new 1939 Act, the Trade Ministry declared by government notice that the Ministry of Public Works should appoint a committee to concentrate electricity production in the most fuel-economic power stations, and thereby save on the national fuel supplies.[60] The competence of this committee was determined by the Minister of Public Works. Chaired by professor Aubeck, however, this committee (the so-called 'Electricity Committee of 1940') was not to apply force. Instead its strategy was to start and participate in negotiations between the utilities on the establishment on the necessary (inter)connections, so that utilities lacking engine power could temporarily draw electricity from utilities with an excess of engine power. In this process, the Committee would support the small utilities in order to prevent that the larger utilities would exploit their position to negotiate excessive electricity prices. It also underlined the temporary character of such (inter)connections: After the war, each utility would be free to take up its decentral electricity production. The final decision was thus again left to the individual utilities, although in case of acute fuel shortages these might not have much choice but to connect to larger systems (see chapter seven). Therefore the intermediation of the Electricity Committee of 1940 proved very successful: Within a few years, 'practically speaking the entire electricity production to towns and hinterland could be situated at fuel-economic steam powered power stations.'[61]

When the war was over, however, most utilities again took up their decentral electricity production. The legal framework was not changed again until the 1970s, when the energy crisis inspired a new Electricity Supply Act (1976). To increase government control with the utilities, this Act introduced a concession system for power stations with a capacity larger than twenty-five megawatts. Its administration resorted under the Trade Ministry (and later the Ministry of Energy), and economic evaluation was taken out of the tasks of the electricity council.[62] By then, however, electricity supply had already been centralized without the support of legislation or State participation.

The actor group of large utilities and the success of centralized supply in Eastern Denmark

The construction of centralized systems, then, was left to the existing actors on the field of electricity supply. Prior to the Second World War, it were in particular the very large utilities that worked for the establishment of centralized supply. As mentioned above, these had different success in different parts of the country: While in Eastern Denmark a handful of large utilities had established a centralized system covering most of the region by the outbreak of the war, in Western Denmark similar attempts had failed, and there existed only two mutually unconnected centralized systems, which covered a minor part of the region.

With regard to Eastern Denmark, centralized supply was primarily established by the five largest utilities. These included on one hand the two municipal utilities of the capital area, the municipal supply company of Copenhagen and that of Frederiksberg. The other participants were the three large rural district utilities on Zealand: NESA in the North-East, NVE in the North-West and SEAS in the South. Later, the two largest utilities on the island of Falster - the rural district utility of Falster FH and the municipal utility of Nykøbing would likewise build part of the system. Otherwise, these five actors established the East-Danish centralized supply system largely without participation of other actors in the region, such as smaller municipal or rural utilities.

Early co-operation in the 1910s

These five large utilities, however, did not plan and construct a centralized system from the beginning. Instead a centralized supply system developed out of a co-operation, which developed gradually in different stages with different motives and technologies at each stage. At a first stage during the 1910s, the four of them developed a rather loose form of co-operation, which was only a peripheral concern for the single utility: While their main concern was to produce electricity to supply their own base-load, the utilities started to exchange additional electricity. A first such co-operation was established between NESA and the municipal utility of Copenhagen in 1911.[63] During the day, surplus electricity from the Copenhagen utility was transported to NESA, the power station of which could not meet its peak demand. And during the night, when demand was low, NESA returned the borrowed electricity to the Copenhagen utility, which shut down its large units and thus avoided overproduction of electricity. In 1916, when NESA had gained access to cheap but irregular supply of Swedish hydropower, the contract between both utilities was adapted, but the idea was still to exchanging or trading surplus electricity only. In addition, NESA negotiated similar contracts of mutual surplus electricity exchange with the municipal utility of Frederiksberg and with the rural district utility SEAS.[64]

Physically, such exchange of surplus electricity only demanded a modest transport capacity, and the co-operation was achieved simply by connecting the existing transmission networks of the utilities at their common border (figure 5.5). For instance, the first connection between NESA and the Copenhagen utility was made by a transformer station (10 kV/6 kV) in Emdrup, at the boundary of the supply areas of both utilities: For this purpose, the six kilovolts transmission network of Copenhagen was slightly extended to this point, where it met the ten kilovolts transmission network of NESA. In case of the connection between NESA and the Frederiksberg utility in 1915, NESA's ten kilovolts transmission network streched already to the workshop at the end of its electrical railroad in Northern Copenhagen; from here, a new cable was led to the main power station in Frederiksberg. When the connection between NESA and the Copenhagen utility was to be extended in 1916, also the latter was connected to this line. Finally, with regard to the co-operation between NESA and SEAS, the NESA transmission network had already reached Taastrup West of Copenhagen, while the transmission network of SEAS had reached North of the provincial town Køge; both parties then extended their networks to Karlslunde, where they were tied together. The connection was first operational in 1919 due to material shortages following the First World War.[65]

By the late 1910s, a co-operation had been established between four of the five largest utilities on Zealand, which via NESA were connected to Sweden. The remaining large district system of the NVE company in North-Western Zealand had not connected, as the distance was judged too large for co-operation sover transmission grids.[66] For obviously the transport capacity on these connections was rather low, partly because the transmission networks were mainly used for supply of the consumers, partly because of the comparatively modest operation voltage of ten or six kilovolts. The technology of co-operation thus reflected the modest ambition of exchanging additional energy.

Grid building in the 1920s

During the 1920s, this co-operation was extended technologically into the first East-Danish power grid (figure 5.6). The construction of interconnections separate from the transmission networks corresponded with the increased ambitions of co-operation and its promotion from a peripheral to a central concern for the utilities involved. In the retrospective words of NESA director Angelo, 'the co-operation could first gain real economic value, if the connecting lines were built especially for this purpose.'[67]

In addition to the 'old' motives of exchanging additional energy and trading additional Swedish hydropower, two new motives inspired the construction of this grid. A first new motive concerned the exchange of back-up capacity between the rural district utilities. The background was a rapid increase in the electricity demand, which caused all three district utilities to expand their respective power stations. In order to achieve economies of scale, they decided to expand with one large turbogenerator each. Just as NESA equipped its new power station with a single large (six megawatts) turbogenerator, NVE built a new power station at the coast in Kalundborg with one large (three megawatts) turbogenerator, while SEAS equipped its power station in Haslev with a new large (2.5 megawatts) turbogenerator.[68] Such large machines, however, would demand equally large machines as back-up in case of break down or maintenance of the first machine. Instead of inveasting each in a second machine, then, the three rural district utilities agreed to rely on each other for back-up capacity. This, in turn, required that the connection between the utilities had a transport capacity corresponding to the sizes of the large turbogenerators.

With regard to the co-operation between NESA and NVE, which were not yet connected, the latter motivated its participation in the co-operation primarily as an optimal solution for its back-up problem for its base load. In the contract between the two utilities of 1921, this new motive was juxtaposed with the 'old' motive of additional electricity exchange, including NESA's access to cheap hydropower:[69] On one hand, the two utilities agreed to share their daytime load in a way, so that the NVE power stations were fully exploited. At night, when surplus hydropower was available, NESA returned the energy by taking over the entire supply of both supply areas, while the NVE power stations were shut down.[70] Technically, the utilities agreed to build each their part of an interconnection for fifty kilovolts, meeting in Kamstrup near Roskilde. The interconnection was operational in 1922.

Simultaneously, the contract between SEAS and NESA was renewed with an eye to increased co-operation.Technically, SEAS should interconnect its power station in Haslev to the NESA-NVE interconnection at Kamstrup, which would become a junction. However, at this stage SEAS only built the new trajectory from the Northern point of its transmission network to Kamstrup for fifty kilovolts (1922), while the remaining trajectory was postponed. For the time being, the new line functioned only as a second 10 kV connection.[71]

A second new motive for co-operation arose in the second half of the 1920s, and involved the concentration of production of additional electricity in the large thermal power plant in Copenhagen. The background was again a rapid growth of the electricity demand. For the three rural district utilities, one option was to increase the production machinery decentrally. Alternatively, increase of production capacity could be concentrated in the large Copenhagen power plant alone. This plant had been designed for large extensions, and the Copenhagen utility had already decided on a major extension with two units of sixteen and twenty megawatts respectively. After 'fierce' negotiations, the parties agreed on the latter option. According to a new contract (1925) between NESA and the Copenhagen utility, the latter would supply its surplus electricity to NESA, which would supply it to the other utilities. NESA then established new contracts of co-operation with SEAS and NVE on regular electricity sale. In an additional agreement in 1928, it was specified that the Copenhagen utility put its surplus capacity to NESA's and thereby the co-operation's disposal.[72] Finally, NESA also increased its imports of Swedish hydropower, so that it could pool surplus thermal power from Copenhagen and cheap surplus hydropower from Sweden whenever it was available.

Technically, to facilitate this co-operation the participating utilities built a number of new interconnections, all for operation at fifty kilovolts. In the capital area, this included a cable from NESA's central transformer station 'Ørnegaarden', via the main power station of Frederiksberg 'Finsensværket', to Copenhagen's main power station 'H.C. Ørstedsværket' in 1926. In 1929 a direct interconnection between Ørnegaarden and the Copenhagen plant was added.[73] Also, SEAS completed the interconnection from Kamstrup to its power station in the South, which was also operational in 1926.[74] And with regard to NESA's import of Swedish hydropower, the transport capacity of the submarine interconnection was increased by means of two new cables also operated at fifty kilovolts. These were taken into use in 1923 and 1929 respectively, and increased the transport capacity from the original six megawatts to forty megawatts.[75]

In addition, the power grid was expanded further South with a trajectory from the SEAS power station to a transformer station in Eskildstrup on the island of Falster. This expansion was to facilitate purchase of electricity by the district utility of Falster. According to a 1927 contract, the Falster district utility would participate directly in the establishment of the grid by financing a submarine cable under the Storstrømmen, and construct the remaining trajectory on Falster. Notably, operation was adapted to the possible access of cheap Swedish hydropower; in the negotiations with NESA, both SEAS and the Falster district utility agreed to not use their own production machinery as long as hydropower could be purchased. The line came into operation in 1928.[76]

By the late 1920s, then, a fifty kilovolts power grid covered most of Eastern Denmark. It resembled the East-Danish part of Faber's 1921 design, and in fact Faber acted as the consultant of the three rural district utilities and thus had considerable influence on the contractual agreements and the technical form of the co-operation.

In addition to the grid, the system included several larger power stations, including the main power stations of the municipal utility of Copenhagen (sixty-four megawatts) and that of Frederiksberg (eight megawatts), as well as the smaller power stations of NESA (six megawatts), NVE (three megawatts) and SEAS (three megawatts). In addition, it included a link (forty megawatts) to Sweden to facilitate electricity imports. Finally, the production of electricity had partly been concentrated, in that additional energy of the other participants was primarily produced in the large Copenhagen plant or - when available - obtained from Sweden. In this sense one can speak of an emerging centralized system, coordinated centrally from the NESA control centre.

When NESA director Angelo evaluated this co-operation in 1927, ten years after his first address to the Danish Society of Engineers on the issue, he proudly refered the economical achievements so far.[77] On one hand, a reduction of the total back-up capacity in the system had resulted in considerable reduction of the investment costs, which more than outweighed the investment in a power grid. And on the other hand, also running expenses had decreased: Load management - enabled through the exchange of additional energy - implied that the three district systems did not have to keep their production machinery running all 8760 hours of the year but considerably less, and when they were started, they were set to run with a more steady load. As a result, both fuel and manpower was saved. Finally, load management facilitated the inclusion of particularly cheap but irregularly avaiable hydroelectricity from Sweden in the supply system.

From co-operation to centralisation in Eastern Denmark in the 1930s

In the 1930s, the co-operation in Eastern Denmark was further developed in the direction of the concentration of production. The motive for the rural district utilities was that it was cheaper to buy also their base load from the Copenhagen utilities than to produce it decentrally. The matter was taken up when the contract between NESA and the Copenhagen utility was due for revision in 1930. In addition, a contract between the rural district utilities arranged the expansion of the power grid for this purpose.

Technically, on one hand the Copenhagen main power plant was further extended to its maximum of one hundred and fifty megawatts, which should make it the largest thermal power station in the Nordic countries. It then practically took over supply of the base load of the rural district utilities, the power stations of which were idle during most of the 1930s. On the other hand, the power grid was expanded (figure 5.7). To facilitate the concentration of production, both the transport capacity and the security of supply had to be increased. A third cable increased the capacity of the interconnection between the Copenhagen power plant and NESA's central transformer station, while the trajectory from this station to the Kamstrup junction was increased from a single to a double connection.[78] Moreover, the central stations of NVE (in Kalundborg) and SEAS (Haslev) were interconnected in a ring system by means of a trajectory from the Kamstrup junction via a new junction near Ringsted, to which both power stations were interconnected. If one link broke down, power would still be available from the other.[79]

By the late 1930s the power grid thus covered most of the East-Danish region, and the production of electricity had been concentrated primarily in the large Copenhagen power plant. Of the power plants of the actors in the co-operation, only that of Frederiksberg maintained a significant production of its own, while NESA continued to import Swedish hydropower when it was available. It should be emphasised, however, that there remained a large number of decentral actors, who co-existed with this large centralized system. A number of independent village utilities and also municipal utilities on Zealand remained physically unconnected to the grid (for instance the municipal utilities of Slagelse, Sorø, Ringsted and Fakse). In addition, several municipal utilities had in some way been connected physically, but maintained decentral production, and used the centralized system only as a source of additional energy supply (including those in Roskilde and Holbæk on Zealand). And on the Southern Island of Lolland, the centralized system was yet of minor importance, despite a physical connection (the towns of Nakskov, Maribo, and Rødby were for instance connected via a connection to Nykøbing on Falster).[80]

Centralized supply in West Denmark

The Southern Jutland utility

One might expect that the largest utilities West of the Great Belt had similar motives to establish a large centralized supply system covering the entire region as their East Danish colleagues. Indeed, these largest actors - the municipal utilities of Denmark's largest provincial towns Odense and Århus as well as the Southern Jutland utility - were inspired by Eastern developments. Yet their attempts to organize a West-Danish centralized system failed, and by the beginning of Second World War only one utility had engaged in centralized supply besides the Gudenaa co-operation. This was the Southern Jutland utility. Notably, this utility did not co-operate with other Danish utilities, but chose to connect to the South to the power grid of Schleswig-Holstein in Northern Germany.

The large Southern Jutland utility had been established during the first half of the 1920s to supply the new territory recently regained from Germany.[81] The initiative largely stemmed from the almost completely unelectrified rural areas, where electrification was regarded as a necessary element of a much desired modernization of agriculture. Around 1920 a handful of large rural consumer associations were formed with the purpose to obtain cheap electricity to their districts. Moreover, the national government was prepared to provide financial support in this exceptional case, provided that electrification included the entire new territory and that electricity production should be situated in Denmark. As the government had rejected the possibility of importing electricity from Germany, and negotiations with larger utilities in the old territory failed, the rural consumer associations and a single municipality of Åbenrå decided to establish a common power station of their own. In 1924 their common production company, the Southern Jutland utility [*Sønderjyllands Højspændingværk*, S. H.], organized as a co-operative society, inaugurated its large district system: Electricity was produced in one comparatively large power plant situated in Åbenrå, and transported to the partners by means of a fifteen kilovolts transmission network. The partners then acted as further transmission and distribution companies.

Like the Gudenaa system, the Southern Jutland system thus started out as a very large district system supplying rural areas as well as towns. But soon it developed into a centralized system. In the late 1920s, the Southern Jutland utility actively sought co-operation with other larger utilities. For as its director Jes Christiansen explained, co-operation was preferable to an extension of the power station: It was such co-operation, that made electricity prices lower abroad than in Denmark.[82] Negotiations with the municipal utility of Århus in the North broke down, but negotiations with the utility of the German border town Flensburg resulted in a contract (1928), which arranged both the exchange of surplus energy and the sharing of mutual back-up capacity. The year after, the Flensburg utility turned over its contractual obligations to the Northern German partnership of the region Schleswig-Holstein *Vereinigte Grosskraftwerke Schleswig-Holstein*, which besides Flensburg included power stations in Neumünster, Kiel, Altona and Hamburg. With regard to the technology, the 1928 contract agreed on the construction of a sixty kilovolts interconnection between Flensburg and the SH power station in Aabenraa. Thereby the SH power station was interconnected to the Schleswig-Holstein grid.[83]

For the Southern Jutland utility, the point of a co-operation with a foreign partner was not to import cheap electricity, as it had been for NESA in Eastern Denmark. Instead, it sought a possibility to extend its production capacitiy less often, but with larger turbogenerators (for instance with a fourteen megawatts turbogenerator in 1931) and thus exploit economies of scale. The co-operation thus resembled that between NESA and NVE: With regard to security of supply, less frequent expansions were made possible because the co-operation provided back-up capacity South of the border. And with regard to load management, the partners exchanged energy so as to exploit the running production units fully. For instance, in the first years of the co-operation, the Southern Jutland utility run its large unit at daytime, providing the surplus electricity to its German partners. By contrast, it shut down its machinery at night, at most Sundays and 'a month or two' during the summer for maintenance, and imported electricity from Germany instead. The Ministry of Public Works had no objectives to this arrangement, provided that the Soutehrn Jutland utility in principle maintained sufficient engine power North of the border to supply its own supply area.[84]

The failure of a West Danish centralized electricity supply system

By the outbreak of the Second World War, however, the Mid-Jutland co-operation and the Southern Jutland utility remained the only cases of centralized supply in Western Denmark (fig. 5.8). To be sure, there had been build other interconnections, most notably an interconnection between the power stations of the five East Jutland towns Kolding, Fredericia, Vejle, Horsens and Odder. Yet these utilities rejected the principle of concentration of production, and used the interconnection exclusively to improve the economy of their decentral power stations (see chapter seven). A similar co-operation was found in Northern Jutland, where three towns maintained their independent small power stations, but also established an interconnection. Finally, several town power stations had been interconnected with hydropower plants in their hinterland to establish what in this study has been characterized as a 'local co-operation'. As a result centralized supply systems covered only a minor part of the West-Danish region.

What, then, obstructed the construction of a West-Danish centralized system comparing to that in Eastern Denmark? One explanation is the failure of the large actors to enroll the municipal utilities of medium and small sized towns in a centralization scheme, in which the latter would purchase electricity from the former. As a result, the construction of the relatively small remaining trajectories between Southern Jutland utility and the Århus utility on one hand and the Eastern Jutland interconnection on the other proved a major hurdle. Still, the large actors in the region could have followed the East-Danish example and build a centralized system themselves, without including the smaller actors. Besides the utilities based in Århus and Åbenrå, the municipal utilities of the larger towns of Odense, Randers and Ålborg were such large actors exploiting rather large power stations. Indeed, several large actors did negotiat repeatedly on interconnection and the establishment of a larger scale system.

Most important, this included negotiations between the Southern Jutland utility and the Århus municipal supply company to connect the two largest systems on Jutland, and thereby establish a North-South Jutland interconnection. Afer the failing negotiations on a Jutland interconnection with the purpose of sharing back-up capacity, which caused the Southern Jutland utility to turn to a German partner instead, the government committee of 1928 drew both parties into a negotiation.[85] After designing its master plan, a subcommittee - including Faber (chair), chief engineer Christian Juul from the Århus municipal supply company, mayor H. Fink from the Southern Jutland utility and Due-Jeppesen from the Odense municipal supply company - had carried out a principal study of the feasibility of the Århus-Åbenrå interconnection, and suggested different models of financing and organisation. Although the bulk of production would be situated in the largest power stations in Århus and Åbenrå, these models also included varying degrees of electricity production in the smaller power stations on the interconnection in the scheme - namely those of the South-Eastern Jutland towns. This reduced the overall economy, but should attract the smaller utilities to join the project.[86]

When the latter critizised the scheme during negotiations in 1931, however, the government committee continued its negotiations with representatives from the Århus utility and the Southern Jutland utility only.[87] They commonly agreed that the small utilities would not voluntarily participate in the construction project, but they might join in once the interconnection had been established. A new investigation, carried out by Faber, Juul and Southern Jutland utility director Christiansen in 1932 indeed showed that the savings on machinery outweighed the costs of a sixty kilovolts interconnection in the period up to 1944.[88] But although a concrete organizational model was worked out in which both utilities would have an equal position with regard to the production of eletcricity, the following negotiations failed again. Officially, the Southern Jutland utility and the Århus utility decided to postpone the project because of the world crisis, which made the assumed increase of the electricity demand uncertain.[89] According to Rasmussen (1982), however, there was also decisive disagreement on the issue, if the co-operation of the Southern Jutland utility with its German partners should be included. While the organizational model operated with an expansion of production capacity in Århus and Åbenrå in turns, the Southern Jutland utility found it unreasonable to expand the Århus power station, if an expansion in Åbenrå would be cheaper thanks to this Southern co-operation. The Århus municipality, however, feared to be overrun by cheap electricity from the South.[90] Under all circumstances, the outcome of the negotiations was symptomatic for the West-Danish co-operation attemps: As Southern Jutland utility director Christiansen sceptically concluded in 1939, 'for the time being it seems, that the electricity produced in Åbenrå cannot endure the cold climate up North.'[91]

Another example of failure to extend centralized supply in West Denmark concerns the co-operation between the large municipal utilities of Randers and Århus. In the early 1920s, the former had a power station twice as large as that of Århus, while the latter had sought to anticipate its growing electricity demand by co-operating with the Gudenaa hydropower plant. But soon the Århus utility again lacked capacity, and it investigated the possibility to draw additional electricity from Randers and thereby postpone the expansion of its own power plant once more. Moreover, it proposed to integrate the Randers power station in the Gudenaa centralized supply system; not only would the Randers power station be interconnected to the Gudenaa interconnection by a high capacity link (fifty kilovolts), but also be maintained in a future co-operation, when the thermal power stations in Randers and Århus could be expanded in turns. While there was agreement on such an expansion in turns, the Randers municipality insisted on a cheaper interconnection operated at twenty-five kilovolts only: The transport capacity of such a line (some two megawatts) would be sufficient for additional energy supply, but not for a full scale co-operation compared to that on Zealand. This line was indeed built, but generally regarded as a failure for the diffusion of centralized supply. Indeed, the interconnection did not gain much importance: In 1928 the co-operation was cancelled alltogether, as the Randers municipality decided to expand its power station although it should be Århus' turn. As a result, both power stations were expanded (Århus finally build a new large power station), and their mutual co-operation remained insignificant until centralized supply was finally established in the 1950s.[92] The large utilities in Western Denmark, in sum, were not able to co-operate on the establishment of a large centralized system without the co-operation of smaller utilities or further incentives imposed on them from outside.

Part II

Actor groups and the consolidation of decentral systems

6
Autoproducers in industry and agriculture

The electricity supply situation after 1920

By the early 1920s, the three electricity supply configurations of autoproduction, local supply and district supply had been introduced and widely spread in Danish society, while a fourth configuration of centralized electricity supply had been introduced in both Eastern and Western Denmark. The latter configuration would expand rapidly in the following decades, particularly in Eastern Denmark. Moreover, the dynamics of these different configurations of electricity supply had been tied up with the engagement and technological choices of different actor groups. Autoproduction systems were maintained by a number of such groups, the most important of which were a number of branches of industry and the group of farmers. With regard to public electricity supply systems, the actor groups engaged were fewer: Local systems were adopted by the two actor groups of municipalities and rural consumer associations, and so were district systems. Centralized supply, finally, was embraced by an actor group of few large and rapidly expanding utilities. The utilities of this latter group in fact might be owned by municipalities or rural consumer associations, like the other public supply systems. But their inclusion in these other actor groups was low, as they demonstrated a preference for large scale systems, and condemned the consolidation of decentral electricity supply. It was also this actor group of large utilities, that defined the dominant discourse on electricity supply in engineering and government circles, which equalled the diffusion of centralized electricity supply with a rationalization of the supply business, and depicted the three older types of electricity supply system as decentral and irrational to be maintained in the long run.

The situation on the electricity supply field after 1920, then, was one of competition between different configurations electricity supply, where the newest configuration of centralized electricity supply was often presented as the ideal. However, as the statistical survey in the introduction showed, the decentral configurations of electricity supply did not structurally loose their position on the electricity supply market until the 1950s. The following chapters investigate this remarkable consolidation of decentral supply systems, primarily by focusing on the motives of the actor groups maintaining such systems and thus rejecting the recommendations from leading engineers, large utilities and government committees to concentrate production in few, large and interconnected power plants. In particular, the investigation will try to be sensitive to the economical and technical arguments for such a consolidation, and thereby scrutinize the verdict of contemporary and later historians of centralized supply that this consolidation was economically and technically irrational and an expression of social momentum, stubbornness or local patriotism.

The actor groups of autoproduction systems after 1920

Among the decentral electricity supply technologies, autoproduction of electricity stood out as a relatively successful one: Despite the increasing success of more centralized forms of electricity supply, autoproduction of electricity continued to increase both in terms of numbers and in terms of electricity output for the entire period under consideration. According to the electricity supply statistics, informed by the registers of the Electricity Council, the number of autoproduction systems increased from some eight hundred systems in 1910 to some twenty-one hundred by 1950, whereafter it stabilized for the next few decades. Simultaneously their total output increased steadily until today, save some exceptional time periods such as the Second World War.

With regard to the first rapidly increasing and later stabilizing number of autoproduction systems, the available sources suggest that there was a change in the importance of the various actor groups responsible for this development since the situation in 1910, which was analysed in chapter two. The few censuses of agricultural machinery, which include aggregate information on agricultural electricity production, point at farms as the primary actor group responsible for the large number of autoproduction systems: A 1944 census recorded no less than two thousand farms with an autoproduction system for electricity supply, while a 1950 census recorded a small reduction to some eighteen hundred farms with their own electricity supply system. This modest decrease was caused by a reduction of the number of farm systems on the Danish islands, while in Jutland, where the majority of farm systems was situated, this number had slightly increased. And an observation from 1960 suggests that this number had not decreased significantly a decade later.[1] Notably, these figures do not include the large number of accumulator powered electric fences (used by some ten thousand farms in 1950), but only generator powered electricity supply systems. It seems, furthermore, that a number of these systems were not registered centrally by the Electricity Council and thus not included in the aggregate numbers presented in the electricity supply statistics.[2]

In addition to these farm autoproduction systems, the business census of 1935 - to my knowledge the only census including the number of industrial autoproduction systems - registered nearly six hundred industrial autoproduction systems. As its concern was to register the power supply of industry and handicraft, however, it probably excluded pure lighting systems.[3] Among the systems registered, particularly large actor groups were some hundred flour mills, some hundred machine factories and iron foundries, some forty bacon factories, twenty-seven wood mills, twenty brick works and twenty breweries.[4]

The numeral dominance of farm systems implied that most autoproduction systems were very small: By 1950, eighty percent of the registered autoproduction systems in the electricity supply statistics had a capacity less than thirty kilowatts. This large majority of small systems accounted for merely fifteen percent of the total capacity of autoproduction systems.[5] Conversely, relatively few, large systems were responsible for most of the capacity and output of autoproduction systems. As in 1910, the cement and paper industries remained the largest actor groups in this respect: According to the 1935 business census, cement factories accounted for 20% of the autoproduction capacity in industry and handicraft, paper factories for 11%, oil mills for 9%, sugar factories for 8% and breweries for 7%. Together these five industries accounted for more than half of the autoproducing capacity in Denmark.[6] And according to the statistics of industrial production of 1951, which only included industrial firms with more than five workers, the nine most electricity intensive industries included the top seven of industrial autoproducers of electricity, which accounted for some 85% of the autoproduced electricity in industry - and the two largest industries of paper and cement accounted for about half (table 6.1).

One may conclude, then, that farms dominated the numeral growth and consolidation of autoproduction systems, while the paper and cement industries dominated the gradually increasing electricity output. These three actor groups will be studied in greater detail below. It is important to note, however, that there is some difference in the homogeneity of these actor groups. On one hand, the actor group of farmers did not as such opt for autoproduction: As there were some two hundred thousand farms in Denmark during the time period in study, only one percent of them chose autoproduction systems, while the rest chose supply from a public supply system.[7] So it was a minority of actors within this actor group, that was responsible for the consolidation of autoproduction systems in Denmark, which complicates the investigation of motives.

A similar observation concerns the group of industry and handicraft as a whole: In 1935 there were some hundred thousand firms in the secondary sector, only half a percent of which autoproduced electric power (yet, others autoproduced steam or diesel power). The importance of autoproduction of electricity increased with the size of the firm: Of the three hundred eighty Danish factories with more than a hundred workers, about one third autoproduced its electric power.[8] But within this sector, the members of the actor groups of the paper and cement industries acted quite homogeneously in choosing autoproduction of electricity: Paper factories autoproduced nearly all their electricity, and cement industries the large majority. Other

Table 6.1: The nine most electricity-intensive industries (defined as firms with more than five workers) with an annual electricity consumption larger than twenty gigawatt-hours in order of their consumption of autoproduced electricity in Denmark in 1951. Electricity supplied to the public power grid is excluded.[9]

	Consumed electricity			% of total industrial autoproduction
	Autoproduced (GWh)	Bought (GWh)	Total (GWh)	
Paper factories	73 (97%)	2 (3%)	75	27%
Cement factories	65 (78%)	18 (22%)	83	24%
Sugar factories	28 (85%)	5 (15%)	33	10%
Breweries	18 (62%)	11 (38%)	29	7%
Oil mills	17 (50%)	17 (50%)	34	6%
Textile factories	15 (24%)	51 (76%)	66	6%
Ship yards	14 (35%)	26 (65%)	40	5%
Machine factories & iron foundries	3 (7%)	42 (93%)	45	1%
Flour factories	0* (1%)	24 (99%)	24	0%
Other	35 (9%)	363 (91%)	398	14%
Total	268 (32%)	559 (68%)	827	100%

* 0.3 Gigawatt-hours.

electricity intensive industries, such as machine factories and flour factories, took an opposite choice in showing a clear group preference for electricity purchase.

General considerations on industrial autoproduction of electricity

The size of autoproducers and the electricity prices of electric utilities

Aware of the fact that conditions of power consumption and supply differed from industry to industry, spokesmen of industry rarely addressed the issue of autoproduction of electricity in general terms - at least not before the issue of rationalization in the public electricity supply sector was increasingly put on the agenda in the Second World War. It is therefore difficult to speak of an industrial discourse favouring decentral production, as for instance in the case of municipal and consumer owned utilities described in the next chapters. The same applies to the group of farms.

However, reasons for the competitiveness of autoproduction system were also identified by spokesmen of electric utilities, although their focus was exclusively upon industry. For instance, at the eve of the First World War NESA director Aage Angelo, a leading agitator for centralized supply, admitted that only very small power consumers - with a power demand up to some twenty horsepowers - bought their electricity from electric utilities. If larger power consumers desired electric drive, they generally preferred to autoproduce their electricity. According to Angelo this behaviour was rational, as the electricity prices of electric utilities were generally higher than the costs of autoproduced electricity. In his view, electric utilities might be able to compete with autoproduction systems only if such autoproduction systems were newly established or expanded: In these cases, the comparatively high investment costs were a competitive disadvantage of autoproduction. But electric utilities could not compete with factories, which possessed sufficiently large and modern power equipment.[10]

In an address to a national industry meeting just after the Second World War, Angelo argued that this situation had hardly changed. In the early phase of electricity supply, industries seeking electrification had no choice but to autoproduce their electricity, because public electricity supply systems generally were too small to supply the demand. During the first half of the twentieth century public supply systems had increased in size, and industry had simultaneously indeed increased its electricity purchases. But larger industrial firms could still autoproduce electricity cheaper than utilities could or would sell it. Angelo particularly blamed the too high electricity prices: On one hand, electric utilities produced electricity too expensive, not in the least due to the 'irrational', decentral structure of public electricity production in the largest part of the country. And on the other hand, these utilities earned too much on their sales, as particularly municipalities - most of which still run their own independent production systems - charged a large profit margin and used electricity supply as a source of income.[11]

Specific conditions for cheap autoproduction

Others pointed at specific industries, which were particularly difficult to attract as customers of electric utilities. Such industries might have specific conditions of production, which made autoproduction of electricity particularly competitive. These specific conditions had already been discussed in electrotechnical circles in the 1910s. For instance, consulting engineer Christian Stau Andresen observed that combined production of heat and power and or a particularly high 'utilization time' affected the comparison with electricity purchases decisively.[12]

With regard to the co-production of heat and power, Andresen found that factories with a large heat demand in the production process, and therefore a large heat production, could autoproduce power with few extra fuel expenses and therefore at low running costs. Andresen identified two forms of combined heat and power production. In some industries, such as the cement industry discussed below, kilns were central in the production process, and their waste heat could be directly used to produce steam in a waste-heat boiler and drive a generator. In such cases, electric power was produced at zero fuel costs, and electric utilities would be unable to compete.

In other industries, such as the butter factories discussed in chapter two, it was the waste heat of a steam engine which could be used in the production process. Other industries with a large steam demand were breweries, sugar factories, weaving mills, many chemical factories, paper factories and also laundries and public baths. All of these used large amounts of steam for boiling, drying or heating air and water. Once produced in a boiler, the steam could be led through a steam engine where a minor part of its energy content was used to produce power, and then further used in the production process. And as another observer described, the connection of a steam engine in the heat flow could also be useful as the pressure had to be decreased anyway: Factories with a large heat consumption would use boilers for rather high pressures to limit the boiler size, but the steam was to be distributed in the factory through a pipe system under low pressure. A steam engine, where the steam expanded while producing power, could lower the high pressure to the distribution level. In any case, power could be produced with disproportionally small increases in fuel consumption and thus very cheaply, which made it difficult for a public supply company to compete.[13]

Also this economic advantage was confirmed by spokesmen of electric utilities. In his address at the World Power Conference in the early 1930s, for instance, the director of the Copenhagen lighting service Johannes Børresen concluded that it would not be possible to persuade large scale industries with a large heat consumption to purchase their electricity, as these always could autoproduce electricity cheaper. Not even the co-production of electricity and heat in public power plants for supply of electricity as well as town heating, which was already frequently practised (see chapter seven), would change this situation, for the high investment costs of external pipe systems made heat supply by utilities comparatively expensive.[14]

As a second specific condition for cheap autoproduction of electricity, Andresen mentioned the utilization time of the power machinery. Some industries might have a much higher utilization time, and thus repay their systems much sooner, than electric utilities. For the latter had a comparatively fluctuating load due to the peaks and throughs of the lighting demand, and therefore a rather low utilization time of the installed engine capacity. The border line for economically feasible autoproduction could not be drawn in general, of course, and depended in each case upon the fuel and electricity prices, the size of the system and its load. According to Andresen, only for very small systems without heat consumption, electricity purchase was unambiguously cheaper; otherwise, it was unplausible to make a general assessment on the feasibility of autoproduction. And as another observer stressed in the 1920s, the utilization time varied very much from industry to industry, some of which run continuous throughout the day and year (such as cement and oil factories), while some run particularly in some seasons (such as sugar factories). And as many factories also used heat in the production process, the economy of decentral electricity production could not be isolated as a variable.[15]

Autoproduction and the rationalization of public electricity supply

The increasing success of centralized electricity supply from the Second World War made industrial autoproduction systems relatively small compared to the larger public power plants. As Angelo had observed, this made the purchase of electricity a technically feasible option - but not necessarily an economical one. Being an electrotechnical engineer but speaking on behalf of large scale industry, in the early 1940s Michael Mogensen of the leading paper manufacturer United Paper Factories, Ltd. [*A/S De forenede Papirfabrikker*] pointed at the continued validity of the economic arguments of combined heat and power production and a high utilization time.[16] Notably, Mogensen did not disagree with government committees and many of his electrotechnical engineer colleagues that the production of electricity for public supply should be concentrated in few large power stations. And with regard to industrial autoproducers, he admitted that factory entrepreneurs were not particularly fond of autoproducing their power: Power production was only a secondary activity to the main production line, and industrial entrepreneurs would prefer to invest their capital in the production line itself, where it gave higher returns on investment than bound in the power department. It was therefore not in the interest of industry to maintain such autoproduction systems, if power could be supplied from public supply companies at similar terms - that is, economically and reliably.

But as there still existed a large number of autoproducers, he contended, this was obviously not the case. Like Angelo (and many others) he found the electric utilities to blame as they maintained too high electricity prices. But he also stressed that many autoproducers could still produce electricity comparatively cheaply. In the case of factories without a significant heat consumption, power could technically be taken from the electric power grid; if many autoproducers chose not to do so, this only in rare cases reflected wrong calculations, underestimating the true costs of decentral production, or (possibly justified) distrust towards the reliability of public power supply. Rather, the main reason for the consolidation of such industrial autoproduction systems was their superior utilization time, which made public supply companies unable to compete on electricity prices: Based upon the aggregates of engine capacity and electricity output of autoproducers published in the electricity supply statistics, Mogensen calculated an average utilization time of autoproduction systems of 2300 hours per year. Public supply companies, by contrast, had an average utilization time of merely 1500 hours, and had thus comparatively high annual costs. And in the case of industries with a large heat as well as power demand, which also characterized Mogensen's own paper industry (see below), he maintained that the decentral co-produce electricity and heat remained competitive to purchase of power. Unless heat was available from a nearby public power plant at acceptable prices, he described the establishment of an autoproduction system for this group of industries as 'the correct and natural choice'.[17]

Co-operation between autoproducers and electric utilities

Finally, Mogensen mentioned the possibility of such autoproducers co-operating with electric utilities, and thereby make use of the existing public supply systems in order to improve the economic feasibility of autoproduction. For instance, industrial autoproducers might in this way obtain cheap back-up capacity, or could purchase small amounts of additional lighting electricity when the factory was idle, for instance on holidays. And a more regular purchase of additional electricity might help to postpone an expansion of the autoproduction system. With particular address to combined heat and power (CHP) autoproducing plants, these might even get involved in a much closer co-operation with the public supply system: The autoproducer might use pure CHP generation in parallel with the grid and thus obtain the maximal advantages of cheap CHP production, while the grid connection enabled the additional purchase of electricity or the sale of surplus electricity. In practice, however, for small systems the investment costs of connection might become too high to make this option interesting, while in case of larger factories the electric utilities generally rejected such arrangements out of fear for disturbances in their systems.

Still, a small number of very large firms indeed developed such a co-operation with the electric utilities, in the supply area of which they were situated. In 1950 just over a handful of utilities held contracts of co-operation with large industrial autoproducers; the Odense municipal utility topped the scale, co-operating with no less than eight industrial autoproducers - two electrotechnical firms, two flour factories, a paper factory, a spinning mill, a butter factory and a sugar factory. Others co-operated with a single autoproducer in their supply area, such as the municipal utilities of Ålborg, Holstebro, Middelfart and Frederikshavn, which co-operated with a cement factory, a briquette factory, an electrotechnical factory and a ship yard respectively. In addition, some utilities received surplus electricity from large autoproducers, including the large cement factory in Nørresundby (see below) and also incidentally a municipal incinerator plant or a gas works.[18] In all cases, the consolidation of autoproduction systems was physically embedded in the public electricity supply system.

Autoproduction and public supply in the cement industry

A first case to illustrate these arguments is the cement industry, the largest industry in Denmark in terms of electricity consumption and also the largest group of autoproducers together with the paper industry. The large electricity consumption of cement factories made autoproduction of electricity attractive, but also made them interesting as customers for electric utilities. For instance, in the early 1910s the electrotechnical journal *Elektroteknisk Tidsskrift* was pleased to present a German cement factory supplied by a public supply company: This particular factory, the next largest cement factory in Germany, was in operation round the clock and had an annual electricity consumption of approx. ten gigawatthours. This was more than any Danish system produced, except for that of the Copenhagen utility. Still, the factory preferred to purchase its power from the electric utility of the area: Due to its large consumption, the conditions of purchase were found more attractive than those of autoproduction.[19]

As described in chapter two, the cement industry in Denmark consisted of few but very large factories, and was dominated by firm Aalborg Portland, Ltd., which in turn was partly owned by the Danish cement factory constructor F. L. Smidth & Co (currently FLS-industries). Competition primarily came from a cement factory under the co-operative movement. It was also decribed that electric drive was rapidly introduced from about the turn of the century. Indeed, by the beginning of the Second World War, almost all action was provided by electric motors (table 6.2). Still, unlike the German factory mentioned above, all eight existing Danish cement factories at the eve of the First World War had autoproduction installations, and maintained them during the following decades.[20] In terms of output, the dominance of autoproduction in the electricity consumption of cement factories remained at some eighty percent in 1950. An increasing yet minor share of this consumption was purchased from public supply companies. The overall consumption of autoproduced electricity in the cement industry increased at least until 1960, whereafter it decreased (see also chapter eleven).

Table 6.2: Some choices of electrification in Danish cement factories 1940-1952
Source: Statistics of Production[21].

	1940	1946	1951/52
Electric engine power in % of total engine power installed:	95%	96%	95%
Consumed autoproduction in % of total electricity consumption:	91%	89%	78%
AC generating power in % of total generating power:	85%	96%	98%

Co-production of heat and power

What made autoproduction attractive in this particular case? To start with, although the combined production of heat and power was less visible in the cement industry than in other industries, the issue was certainly relevant. Surprisingly, in the early 1920s the Technology Committee under the Ministry for Domestic Affairs had classified the cement industry as a 'non-combined heat and power producer', and thereby as an industry likely to benefit from public electric power supply.[22] The committee found that the consumption of steam from the boilers for heating purposes was limited. Thereby it obviously overlooked the possibility of applying the waste heat in the exhaust gasses from the kilns to generate power. Such waste heat boiler technology had been (unsuccessfully) pioneered already before the turn of the century, and received 'almost universal attention of cement manufacturers' by 1915 in the United States.[23] In Denmark, F.L. Smidth & Co had started research on this technology and installed waste heat boiler systems in several Danish cement factories shortly after the First World War, including the Aalborg Portland's large Rørdal factory near Ålborg at the Southern bank of the Limfjorden.[24]

In the early 1930s, waste heat boiler technology was still referred to with optimism.[25] By the late 1930s, however, it received less attention. It was observed that the waste heat boiler system gave considerable fuel savings, but also that it had its disadvantages: It proved complicated to operate, and the dependence of the boiler operation upon the kilns constrained the steady operation of the power station.[26] In addition, other methods of energy conservation had become more important. This included particularly more power-efficient grinder designs and more heat-economic kiln designs. For instance, the exhaust gas temperature in F. L. Smidth kilns was reduced from approximately 550 degrees Celsius in the late 1910s, via 200 degrees in the late 1930s to the near minimum of 130 degrees (just before condensation effects) in the late 1940s. This development obviously decreased the feasibility of waste heat boilers. Instead, the remaining waste heat of the rotary kilns was now employed for other applications than for electricity production, such as factory heating and drying of the hardcoal (and, later, town heating).[27]

Several decades later, the issue of combined heat and power production was reopened at the Rørdal factory. With the change from coal to crude oil as a primary energy source, the factory suddenly had a large steam demand to preheat the low-quality oil in the oil tanks, so that it could be more easily transported in a pipe system and burned in the boilers. The factory therefore adapted its power station to the co-production of heat and power from the boilers. Together with the fact that the power machinery had by now been written off in the balance sheet, the low running costs of the system became an argument for the consolidation of the autoproduction system until the early 1990s.[28]

Size and utilization time

In other cases, it was emphasised that the size of consumption and the long and steady power demand of cement factories were the main reasons for maintaining autoproduction of electricity. This concerned for instance the co-operative cement factory in Nørresundby at the Northern bank of the Limfjorden.[29] In the first half of the century, this factory had a much larger power station than the public supply company of the area, the municipal supply company of Nørresundby: While the latter had an engine power of less than one megawatt in 1925, the cement factory had recently erected a new power station with two three megavoltampère turbogenerators, one of which was for back-up. Indeed, when it turned out that the factory only needed half of its operational capacity at the time, the parties agreed that the municipality purchased the surplus electricity production of the factory for supply of the town. From then, the municipal power plant was used as a back-up station only.

Moreover, the steady load of the factory was particularly emphasized as the decisive factor for an extremely cheap autoproduction of electricity, even if the varying load of the Nørresundby municipal utility was included. For while municipal power plants were judged to exploit in average fifteen to twenty percent of their engine power since they had to be designed after the peaks of the lighting load, the cement factory plant supplying both the factory and the public might still exploit forty percent of its engine power (equal to a utilization time of 3500 hours of the operational capacity per year).[30] When the load peaked due to the electricity demand of public lighting, the Nørresundby municipal power station had earlier been forced to start back-up engines. The cement factory, however, simply managed this peak load by turning off some of its power intensive grinders, and thereby maintained a steady load for the turbogenerators.

Thanks to its size and load factor, the co-operative factory then became a major autoproducer of electricity, and also an important supplier of electricity to the public in the Vendsyssel supply region (that is, Northern Jutland above the Limfjorden, see fig. 6.1). From 1925 the factory supplied the Nørresundby municipality and its

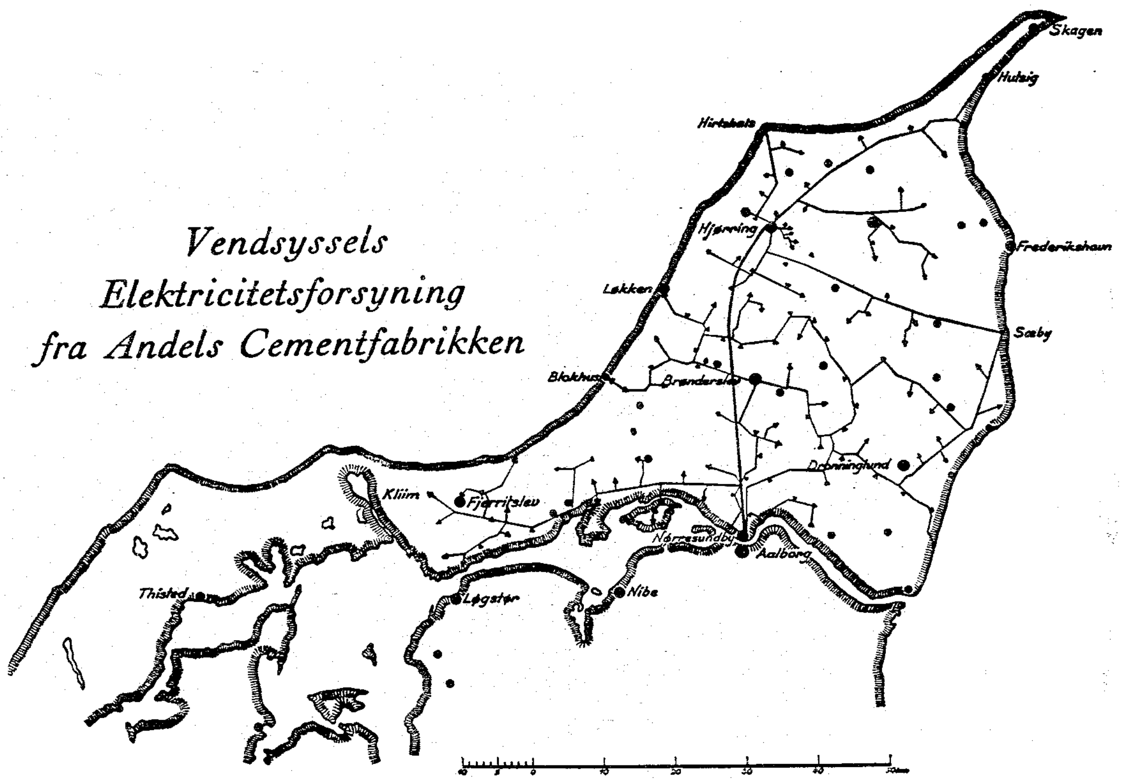


Figure 6.1: The Vendsyssel electricity supply region (roughly Northern Jutland above the Limfjorden) was largely supplied by surplus electricity from the co-operative cement factory in Nørresundby at the northern bank of the Limfjorden. Notably, Aalborg Portland's Rørdal cement factory was situated few kilometres East of Aalborg at the southern bank of the Limfjorden, and thus belonged to the Aalborg municipal supply region (which roughly covered Northern Jutland below the Limfjorden). Source: Holst 1932, 81.

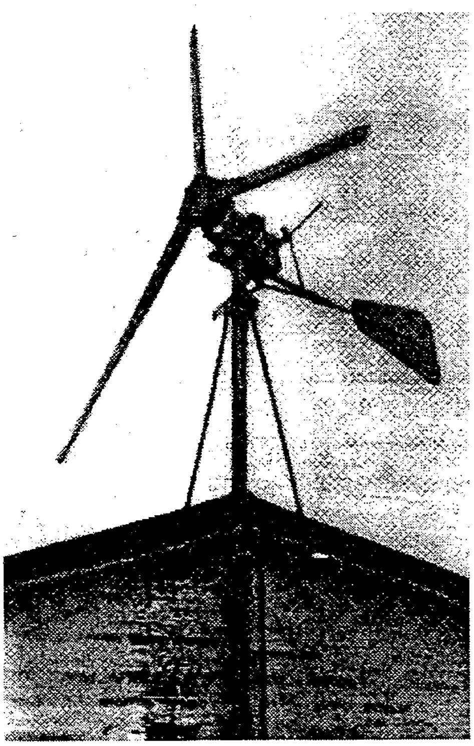
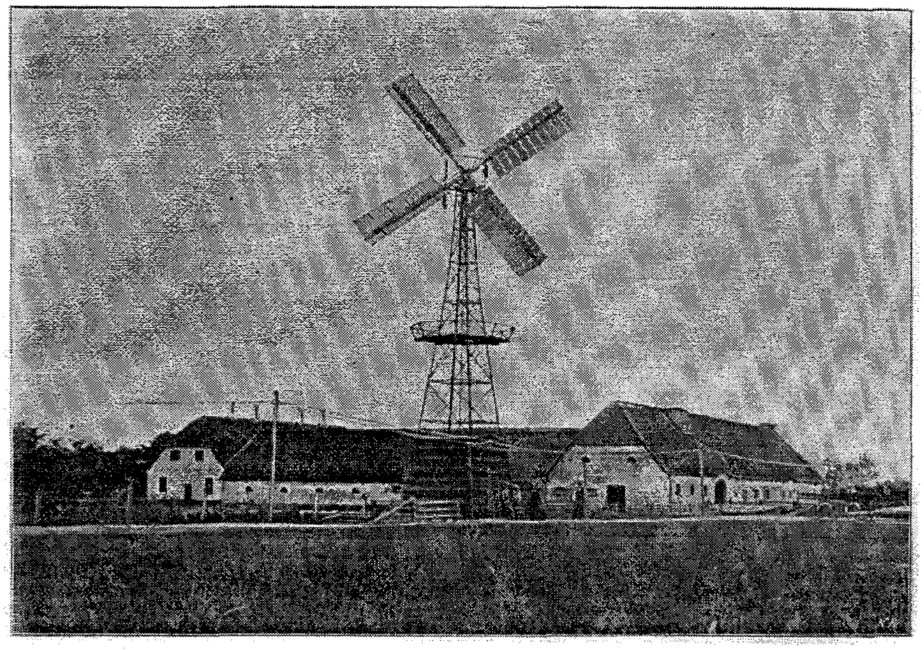


Figure 6.3: Small windgenerator placed upon a roof top. Source: Christiansen 1940, 614.



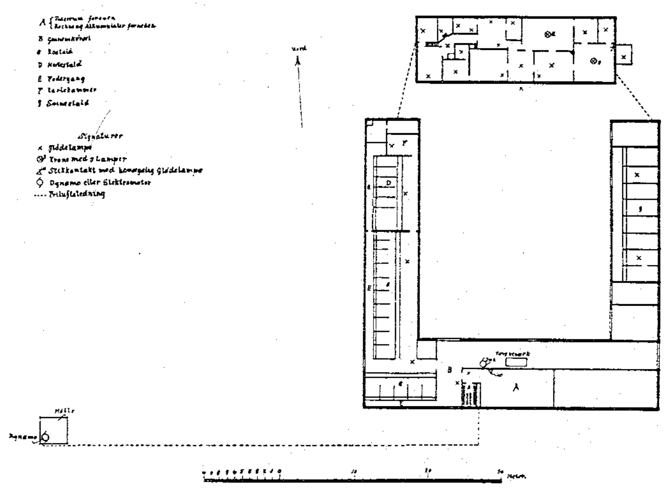


Figure 6.2a-b: The wind-electric autoproduction system of J. Boesen's farm in Askov in 1904. Legend to fig. 6.2b: The farm consisted of a farm house (at the top) and a U-shaped building with cow, horse and pig stables (C, D, G), fodder room (A) and a room for farm-hands (F). The autoproduction system: □= windmill ['Mølle'], ---- = electric wire, x = incandescent lamp, 'tærskeværk'= electropowered threshing machine, A= Accumulator. Source: Tidsskrift for vindelektrisitet 1904, 50 and 54.

surroundings, and by the mid 1930s supply had been extended to the towns of Hjørring and Brønderslev and their respective hinterlands. The municipal utilities of these latter towns purchased more than half of their electricity demand from the Nørresundby utility, which bought it from the cement factory. For the cement factory, this meant a sale of about a fourth to a third of its electricity production. In 1935, for instance, it sold some seven gigawatthours out of the eighteen gigawatthours it had autoproduced. The total production of the factory was therefore not only much larger than that of the combined production of public power stations in the Vendsyssel region, but also larger than the production of the large Aalborg municipal power station (some fifteen gigawatthours) at the Southern bank of the Limfjorden, that is, the public power station of one of the largest province towns in Denmark, which supplied the Northern Jutland supply region south of the Limfjorden.

The paper industry and the rationality of autoproduction systems

By 1950, the paper industry had become even a larger autoproducer of electricity than the cement industry. As mentioned in chapter two, during the period under consideration there were only between ten and fourteen paper factories in Denmark, dominated by the firm United Paper Factories which owned the six of them. These factories also had a very large power demand, which stemmed from the rotation of chopping machines and blenders of raw material in the preparation department, the drive of the huge paper making machines consisting of belts and rollers, several machines in the finishing department, and transport machines between the departments. During the 1940s, these machines were nearly completely driven electrically (table 6.3): About eighty to ninety percent of the motor power installed was electric, excluding of course engines used exclusively for electricity production.[31] Almost all this electric power was autoproduced even in the early 1950s, when a modern electricity supply structure had largely been established throughout Denmark. During the 1950s the autoproduction output of the paper industry still increased (from seventy-three to eighty-three gigawatthours annually), whereafter it stabilized.[32]

In part, also paper factories required power on a scale, which early public supply stations would not be able to provide. Still, by the 1940s and 1950s public supply was available from very large public power stations; unlike cement factores, which were situated in Northern Jutland where the decentral public supply structure was maintained for a long time, paper factories were situated at places where centralized public supply became available early, including factories on Zealand and in Mid-Jutland.

According to United Paper Factories' (UPF) engineer Michael Mogensen, it was

Table 6.3: Some choices of electrification in Danish paper factories 1940-1952. Source: Statistics of Production.[33]

	1940	1946	1951/52
Electric engine power in % of total engine power installed:	85%	88%	93%
Consumed autoproduction in % of total electricity consumption:	98%	97%	97%
AC generating power in % of total generating power:	46%	46%	62%

the large heat demand combined with the large power demand that made autoproduction of electricity attractive in the paper industry. As mentioned in chapter two, large amounts of steam were required in the drying section of the paper making machine: Here, the continuous paper sheet was passed through a number of heated rollers, which evaporated the water and reduced the water content of the sheet from two-thirds to merely a few percent. Technically, steam from the boilers was led through a pipe system to the paper making department, where the steam was led through the metal roller stands and heated them from within. As a result, paper factories had the possibility of combined production of heat and power: In Mogensen's words, it was possible "in an economical fashion to combine heat production with the production of power consumed in the enterprise, which currently is solely distributed with the aid of electricity."[34]

UPF's newly erected factory Ny Maglemølle near Næstved on Southern Zealand in the late 1930s is illustrative.[35] The area was covered by the district utility of South-Eastern Zealand SEAS, one of the largest Eastern Danish utilities, which engaged early in the construction of the East-Danish centralized system. At the time, SEAS indirectly bought about all its electricity cheaply from the large Copenhagen public power plant (with a capacity of one hundred and sixty megawatts) or from Swedish water power plants. In addition, it was preparing the establishment of a very large power plant of its own (fifty megawatts). Still, the paper factory chose to erect its own power station, which was small (about six megawatts) relative to these very large power stations, but started regular operation in 1938.[36] Likewise, another large UPF factory, the Dalum paper factory near Odense, erected a new (four megawatts) power station in the late 1940s despite the proximity of the much larger (twenty-seven megawatts) municipal power plant in Odense, which in turn had been interconnected with the very large (eighty-six megawatts) power plant of the

Southern Jutland utility.[37] It was the possibility of combined heat and power production, that made such relatively small power stations feasible.

Technically, autoproduction systems in paper factories were designed to be relatively simple and robust, and therefore easy to survey and maintain, so that the maintenance costs could be minimized. According to Mogensen, this was more important than the further improvement of the fuel economy. As a result, paper factories might for instance choose simpler boiler preheating constructions than were technically possible, and which the newest public supply plants would prefer.[38] With regard to the combined heat and power production, in the Ny Magelemølle and Dalum factories steam for heating purposes was not taken directly from the boilers, but would first perform labour in a two-chambered steam turbine, which was connected directly to the electricity generator. The turbogenerator contained several steam outlets: Steam for the main heating purpose of paper drying (other applications were glue boiling and factory heating) was taken from an outlet between the two chambers, and thus performed labour in the high pressure chamber before it was led through an underground channel to the paper making department of the factory. The amount of drying steam as well as its temperature could be regulated precisely (the latter was achieved by blowing condensation into the steam). The rest of the steam continued to perform labour in the low pressure chamber and was led to the condenser, which - characteristically for the large steam outlet - was designed only for a half resp. two-thirds of the power generating capacity of the turbine.

With regard to power distribution, these factories used high voltage (10 kV), alternating current distribution of electricity through the factory. Still, direct current distribution was maintained in parts of the factory, as direct current motors with their superior regulability were preferred in the paper making machines. In UPF's new Copenhagen factory in the early 1930s, for instance, most motors were directly fed by alternating current from the main feeder. But the electricity was converted to direct current in the paper making department, and subsequently fed into a common backbone for all fourteen section motors of the paper making machine.[39]

Finally, also paper factories might exploit the availability of public electricity supply systems to improve their economic performance. For instance, the Ny Maglemølle and Dalum factories had interconnecting links with the public supply undertakings of their respective districts and contracts specifying the terms of co-operation: On one hand, the public supply system was used as a back-up system, and electricity could be purchased on Sundays and holidays, when the factory machinery was turned off. On the other hand, on weekdays surplus electricity could be sold to the public supply company. Such co-operation was maintained while the public supply systems grew: In the case of the Dalum factory, for instance, co-operation with the public supply system started as early as 1917 to support the local public power station of Dalum-Hjallese through wartime supply shortages. Through this station, the factory later co-operated with the large Odense municipal supply company, and when the centralisation of electric supply was completed in 1953 with the establishment of a new central public power station for the entire island of Funen, co-operation was continued with the Fynsværket partnership running this system.[40]

The further diffusion and consolidation of farm autoproduction systems

Finally, a last case for more detailed investigation is that of farm autoproduction systems. Farms were on one hand responsible for the large majority of Danish autoproduction systems, while on the other hand autoproduction hardly played an important role in farm electrification: By 1950 the large majority of Denmark's some two hundred thousand farms (which in this chapter includes manor houses) had been electrified; ninety-six percent had electric lighting, while seventy-three percent used electric drive. But less than one percent of all Danish farms autoproduced their electric lighting or power, while the actor group of farmers as such massively opted for purchase from a utility, of which they often were co-owners through a co-operative society.[41]

A further specification of the group of farm autoproduction systems by geography or size does not reveal a particular dominant actor group within the group of farms. The census of agricultural machinery of 1944 allows for such an analysis: With regard to the geographical distribution of farms with autoproduction systems, certainly most of such farms were situated on the Danish mainland. Yet this did not result from an overrepresentation of autoproduction systems at Jutland farms, but simply from the fact that two-thirds of all Danish farms were situated here: In Jutland as well as on the Danish islands, about one percent of the farms had an autoproduction system (table 6.4). The agricultural census of 1950 further specified that most farm autoproduction systems were situated in Eastern Jutland (twenty-nine percent) and Western Jutland (twenty-seven percent), but also that these areas only had a marginal overrepresentation of autoproduction systems relative to the number of farms.[42]

With regard to the farm sizes measured in terms of attached land area, the distribution of farms with autoproduction systems was also rather even in 1944 (table 6.5). Large farms were more likely to have an autoproduction systems than smaller ones; some eleven percent of the farms larger than one hundred and twenty hectares had an autoproduction system, while only one percent or less of farms smaller than thirty hectares had one. Still, ninety percent of the Danish farms were smaller than thirty hectares, and small farms still accounted for some sixty percent of all farm autoproduction systems.

Table 6.4: Farms (incl. manor houses) with autoproduction systems and with electricity producing windmills by geography according to the 1944 census of agricultural machinery.[43]

	Islands (incl. Zealand, Falster, Lolland and Funen)	Jutland	Total
Nr. of farms:	76.436	133.253	209.689
Nr. of farms with autoproduction systems:	673	1.335	2.008
Farms with windmills for electricity production:	585	869	1.454

Table 6.5: Farms (incl. manor houses) with autoproduction systems and with electricity producing windmills by land area according to the 1944 census of agricultural machinery. The source is sometimes inconsistent in including more small farms with electricity producing windmills than with autoproduction systems.[44]

	Farms with a land area of (in hectares):						Total
	0.55-5	5-10	10-30	30-60	60-120	>120	
Nr. of farms	49.193	54.207	80.253	21.648	3.409	979	209.689
Nr. of farms with autoproduction systems (approx):	200	300	900	400	100	100	2.008
Farms with windmills for electricity production (approx):	300	400	600	100	40	40	1.454

Wind-electricity and the rise of farm autoproduction systems

The census does give the clue, however, that wind energy was a primary energy source of Danish farm autoproduction systems, particularly for smaller farms. This dominant role of wind-electricity was typical of the fuel scarcities of the Second World War (although the total number of farm windmotors was decreasing[45]). But wind-electric farm autoproduction systems were more than an emergency solution. To start with, the very emergence of farm autoproduction systems in the first decade of the century had already been tied up with wind-electricity. As described in chapter three, the issue of electrification was brought on the agricultural agenda, particularly due to the efforts of professor Poul la Cour of the Askov folk high school. He developed a rhetoric repertoire which connected rural welfare with rural electrification; a technically and economically feasible electricity supply system based upon windpowered production of low voltage, direct current electricity; and he started the

DVES company in 1904 to promote the diffusion of such systems (and also systems with other power sources) by propaganda, by education of operators and electricians and by offering consultance. Although the focus in la Cour's rhetoric was upon local electricity supply systems for villages, he also stressed that wind-electric systems were appropriate for autoproduction on single farms. Farmers indeed took up this technology, and in this sense the early establishment of farm autoproduction systems can at least partly be seen as a 'spin-off' of public electricity supply technology.

Correspondingly, the establishment of farm autoproduction systems from the beginning did not only involve the choice to electrify agriculture, but also the choice of autoproduction instead of public supply. In the view of la Cour and other early agitators for rural electrification with inclusion in the co-operative milieu, farm autoproduction systems were justified by the desire for electrification in the absence of public electricity supply. Already in 1903 la Cour stressed that his wind-electric system might be appropriate for rather isolated farms, that is, farms situated away from villages and thereby out of reach of the low voltage distribution systems of local village systems.[46] A decade later one of the first Danish educated electrotechnical engineers (1910) and la Cour's successor in Askov, Jens Terkelsen Arnfred, could observe that 'in the current situation, farm systems are only an emergency solution for those, who cannot obtain the advantages of electricity in another way'. He found that village wind-electric systems could produce cheaper than farm systems. According to Arnfred, the evaluations of farmers with autoproduction systems to the DVES company confirmed this view: They generally expressed satisfaction with the economical and technical feasibility of their autoproduction system, but also acknowledged that if public supply systems were available, electricity would become cheaper.[47]

Still, wind-electric farm autoproduction systems became one of the early successes of the DVES company. After the first wind-electric village systems had been designed in 1902 and 1903, the DVES company took the initiative to establish a pilot farm system at the farm of J. Boesen in Askov. The pilot system enabled the company to adapt its windmill and dynamo designs, and it was operational in 1904, including a windmill of la Cour's design and an accumulator to take over supply in windstill periods. It supplied some thirty-five electric incandescent lamps, mostly in the farm house, and a single electromotor, which could drive the chaff cutter, the oil cake crusher, the grinder or the threshing machine (figure 6.2). The system had cost some four thousand DKK, half of which was for the windmill.[48]

From then, farmers and manors approached the company for such autoproduction systems. Early systems included a very large system of nearly six hundred lamps at the Ravnholt manor house on Funen (costing twenty-eight thousand DKK); a system of fifty lamps and an electromotor, which could be plugged in at the threshing machine or the fodder grinder of a manor house near Kolding (price: five thousand DKK including a new windmill); and a farm system supplying some forty lamps and a small motor at a farm in Ejlby in Northern Funen (price: three thousand DKK, excluding an existing windmill).[49] In the following years more interested farmers followed, and by the end of 1906 the DVES company had designed nearly twenty farm systems, besides an equal number of local village systems and a slightly higher number of other autoproduction systems in dairies, factories and schools.[50]

The few published evaluations of these systems confirm Arnfred's impression of the feasibility of wind-electric farm autoproduction systems. For example, after three years of operation the owner of the manor house system near Kolding recommend the further establishment of autoproduction systems in rural Denmark: Although the running costs of wind-electric power were not negligible (due to spare parts and maintenance of the mill), the 'pleasure and use of the autoproduction system overruled the running expenses.' The 'nice light' and 'reliable power' increased the productivity, and reduced the danger of fire. Yet he made the reservation, that common supply from a co-operatively owned public supply system was unavailable. If such systems were available, he recommended the purchase option, as such a co-operative enterprise would always be cheaper for the individual consumer, who only had to be concerned with wires and motors and not with electricity production itself. In addition, public utilities also offered electrotechnical assistance.[51]

By contrast, the farmers Jens Pedersen and P. C. Hansen emphasised the economic savings of the autoproduction system, which they jointly exploited since 1905. After two years of operation, they could observe annual savings of some twelve hundred DKK compared to the traditional lighting and power systems. With such annual savings, the investment of a farm autoproduction system could rapidly be repaid. Largest were the savings on threshing, where fuel expenses disappeared and only labour costs remained compared to previous steam powered threshing. Also important were the savings on corn grinding, which previously had been done by the local village miller. And electric lighting gave significant savings on labour costs - besides qualitative advantages, as it freed the women at the farm from daily cleaning and filling of paraffin lamps.[52]

Finally, it must be noted that others made similar investigations without the DVES company and possibly with other types of autoproduction systems. For instance, the manor house 'Høvdingsgaard' also had an autoproduction from 1903, but used a petrol engine and a steam engine to run two dynamos. In 1904 the manor house made several tests to compare the new power source to traditional power by locomobile. The variables were the fuel demand and the productivity. These factors were for instance affected by irregularities in the manual feeding speed of corn into the threshing machine, which might cause the machine to block: In case of locomobile steam power, the power consumption of the threshing machine would rapidly increase and its speed be reduced, while in case of the much more regulable electric drive, the speed of the threshing machine could constantly be adapted to the corn feeding speed, and such problems be avoided. Indeed, the tests showed that electric drive gave a reduction in coal consumption by fifty percent, while the productivity of the threshing machine was increased by thirty percent.[53] Thus, also steam powered farm autoproduction systems might be technically and economically feasible, particularly if public electricity supply was not available.

The further diffusion of wind-electric farm systems

More surprising than this first diffusion of farm autoproduction systems, which occurred in a time when public electricity supply was often unavailable, is their continuous diffusion in the following decades: For although Arnfred had dismissed the electrification by wind-electric farm systems in 1916, since the development of the internal combustion engine made windpower as a rule technically and economically unfeasible, the number of farm autoproduction systems increased from some eighty systems around 1910 to some two thousand systems by the end of the Second World War, most of which were wind-electric systems.[54]

Partly stimulated by the two World Wars, windmill technology for electricity production remained a field of technical development in Denmark, and could continue to produce small size 'spin-offs' for farm autoproduction systems.[55] By 1910, wind-electric systems might use la Cour's model, a four or six winged windmotor on a slender metal stand. Alternatively, they might use existing older windmill types such as the American type windmotors, with turbine-like wings on a metal stand, or incidentally even existing large tower mills, the so-called Dutch windmills, which were not constructed anymore. In the following years, also propeller mills were introduced, starting with Johannes Jensen & Povl Vinding's so-called Agriccolo mill developed during the First World War. While Dutch windmills had an efficiency (exploitation of the available wind-energy) of about six percent, American windmotors of some seventeen percent and la Cour's windmotor of some twenty-three percent (measured in the 1920s), this propeller mill had a large efficiency of forty-three percent. Besides, whereas previous mills produced direct current for isolated systems, this mill could drive an alternating current generator for electricity supply to the power grid. A larger scale propeller mill was developed by the F. L. Smidth company during the Second World War for use by electric utilities, and from the late 1940s Johannes Juul adapted the design resulting in the famous 200 kW Gedser mill of the late 1950s, designed to supply windpower to the power grid. From the 1970s, this design would be the foundation for the emerging Danish production of wind-electric mills which currently dominates the world market.[56]

With regard to wind-electric systems available to farms, American and la Cour windmotors were kept in production by several companies and independent mill constructors. Like the early Agriccolo propeller mill, these were used to perform many other tasks, such as driving agricultural machines at the farms and pumps in the field - the market for electricity producing windmills had remained comparatively small.[57] But in the beginning of the fuel scarcity in the Second World War, several Danish producers took up the production of very small propeller mills, the so-called 'windgenerators', particularly designed to supply lighting electricity at individual farms and houses. Incidentally, they might also satisfy small power demands such as that of milking machines. Moreover, these systems received ample attention and thereby recommendation in agricultural circles: They were praised in the 1940 and 1946 editions of the authoritative handbook of agricultural machines [*Det danske landbrugs maskinbog/Maskinbog for landmænd*], and the state board for agricultural machinery performed official tests of the windgenerators in regular production in 1941.[58]

Important advantages of such windgenerators were their small size and their low costs. Knud Hansen of the state board of agricultural machinery estimated that a windgenerator of two hundred watts with given wind speeds could in average supply a capacity of a hundred watts, and thus produce 2.4 kilowatt-hours daily. This was sufficient to supply an electric milking machine for some two hours, and besides supply five incandescent lamps of forty watt in six hours. Still, if the system was used for milking machines, he recommended a back-up engine or an overdesigned accumulator capacity to meet periods or low wind. In addition to the cost decrease resulting from their small physical size, the costs of windgenerator systems were decreased to a minimum for instance by using car dynamos and accumulators, and by placing the dynamo at the mill top to save on heavy and expensive transmission axles and reduce transmission losses - a design which was known from the United States since the mid 1920s. Examples of such small windgeneration systems include the very small 'King' windgenerator, which had a propeller diameter of merely one and a half metre, was mounted on a metal stand of merely two metres, and used a T-Ford car dynamo of ninety watts. Without an accumulator, this system cost merely 325 DKK. And the larger 'Richmond' windgenerator only had a propeller diameter of some three and a half metres, a capacity of 1650 watts, and cost over three thousand DKK.

Already in the early 1940s it was observed that a considerable number of such small wind-electric systems were adopted by farms, particularly those which had a petrol powered autoproduction system already, and which were situated relatively far from electric utilities. Notably, 'a large number' of such mills had been 'autoconstructed' by the single farmer using available car dynamos. Thanks to their small size, these windgenerators could simply be placed upon roof tops (figure 6.3).

Tractors, pig farms and post war farm autoproduction systems

It is remarkable, that also after the Second World War the large number of farm autoproduction was maintained. By the mid 1960s the total number of autoproduction systems was still at two-thousand, despite the fact that public electricity supply had been nearly completely centralized, and high voltage transmission networks reached everywhere around the country. To my knowledge, there are no statistics indicating how many of these were farm systems, and if windgenerators were maintained. But incidental reports suggest that windgenerators indeed might be maintained due to their very low running costs.[59]

Moreover, another motive for maintaining small farm autoproduction systems in general, regardless if these used windgenerators or engines, appeared with the introduction of the tractor. In the post war period, the introduction of tractors certainly marked a revolution in Danish agriculture: By the end of the Second World War, only six thousand farms had their own tractor, but ten years later about half of all Danish farms had one.[60] By the early 1960s, professor at the Royal School of Agriculture H. Rosenstand Schacht could observe that 'the tractor is the key machine in Danish agriculture'.[61] The context for this innovation was the post war mechanization of agriculture, where on one hand international competition made human labour too expensive, while on the other hand this labour was attracted by higher wages in towns. Two decades after the Second World War the number of farm hands had halved, and by the early seventies most farms did without. Simultaneously, tractors and a range of new machines were rapidly introduced.[62] Indeed, tractors proved multi functional for farm and field work: They were not only suited to pull field machinery, but also equipped with mechanical and hydraulic lifting gear, had one or two power pulleys for belt drive of machines, and possibly more special purpose machinery such as pumps, compressors or welding generators. They might even be equipped with electricity generators for electric machine drive, and thus form mobile autoproduction systems. Such tractor-electric drive had been introduced in the United States, and in Denmark the agricultural machinery section of the Royal School of Agriculture and the electrotechnical manufacturer Thomas B. Thrige jointly developed a generator for tractor-electric drive during the second half of the 1950s, although at that time they could observe little interest from tractor producers.[63]

This rapid introduction of tractors, however, might also affect the consolidation of stationary autoproduction systems. This argument was for instance made by agricultural state consultant Niels Balle in the 1946 edition of the handbook of agricultural machinery.[64] In an attempt to formulate general guidelines for the choice of agricultural power supply, he included the combination of small autoproduction systems for electric lighting and a tractor to supply power both to farm and to field machines. In his view, this combination made small autoproduction systems for electric lighting feasible also in peace time. To illustrate this point, he compared a scheme of light and power supply from an electric utility from a transformer station at two kilometres distance, with a scheme of power supply from a tractor and light supply from an electricity autoproduction system. Notably, although Balle was well aware of the production of windgenerators for farm lighting, he chose an autoproduction system powered by a small petrol engine (of six hundred watts); the comparison was thus not distorted by the high fuel prices. The calculation showed that the combination of a tractor and an autoproduction system was slightly cheaper than the electricity purchase scheme in annual costs, despite slightly higher investment costs. Its disadvantage was that tractors did not provide a similarly regulable and comfortable drive as electric motors. On the other hand, the tractor could also be used for field work, which was to the advantage of the combined tractor and autoproduction scheme. The availability of tractor drive thus may have been an incentive for agricultural autoproducers to maintain their systems for lighting only.

Finally, another motive to maintain autoproduction systems in agriculture concerns the increasing dependence of agricultural production on electricity supply, which in several cases made autoproduction systems necessary as back-up systems to purchase of electricity from utilities. This was particularly so for farms specializing in pig or chicken production. With regard to pig production, which was concentrated in large pig stables, ventilation was crucial. It was already observed during the 1950s that the fodder consumption in well ventilated stables was significantly reduced. Moreover, it was observed that in case of a ventilation break down the temperature rose rapidly, and after merely half an hour might be lethal for piglets.[65] Chicken farms had a similar concern, as they used electric chicken brooders. In the mid 1980s, a publication of the Danish association of utilities observed that despite the exploitation of mobile emergency generators by electric utilities, 'many farms' had acquired back-up systems of their own, as even short black-outs could have catastrophal consequences in pig and chicken farms.[66]

The three cases of cement industry, paper industry and farms illustrate that the variety of concerns, which had characterized the introduction and diffusion of autoproduction systems, also gave different motives for their consolidation. Still, with regard to the increasing electricity output of autoproduction systems, the economic motives stemming from on one hand large scale production with a high utilization time, and on the other hand of combined heat and power production, prevailed. These concerns also counted in a number of other industries. For instance, the electric wire manufacturer *Nordisk Kabel & Traad fabrik*, with factories in Middelfart on Funen and in Frederiksberg in the capital area, recognized at the eve of the First World War that its very modern and medium sized (over a hundred kilowatts) autoproduction system in the Frederiksberg factory could not produce very cheaply due to the high investment costs. When an expansion was necessary, it chose instead to purchase additional electricity from the municipal supply company of Frederiksberg. However, it also maintained the old autoproduction system, partly because of its use of steam in the production process, and partly not to be dependent upon the public utility.[67] And Burmeister and Wain, exploiting the largest autoproduction system in Denmark's largest machine factory, doubted that purchase was attractive because of the size of its power consumption and its large steam consumption: The machine factory produced no less than two-thirds of its steam for other purposes than electricity production, not in the least for its forging presses.[68] Finally, heat was important in many food industries for boiling purposes, and by 1980 the food industry (including breweries) accounted for almost half of the autoproduced electricity in Danish industry.[69]

7
The municipalities and the consolidation of town systems

Local and district town systems

Like autoproduction systems, also local and district systems for public electricity supply were generally maintained at least three decades after the introduction of centralized supply. Only from the 1950s the two actor groups involved, those of urban municipalities and rural consumer associations, rapidly abandoned such decentral public supply systems. The choices of the former actor group primarily affected the dynamics of decentral town or town-based systems (table 7.1). The number of local town systems, about half of which were run by municipalities still in 1950, was stable at some seventy systems until the Second World War and had only marginally decreased by 1950. Moreover, from the early 1920s to 1950 the output of such systems about doubled. The number of town-based district systems, nearly all run by municipalities (possibly in co-operation with hinterland consumers), was even more stable at just over thirty systems until 1950, and also their output increased gradually. As these town-based district systems were much larger than local town systems, they accounted for the bulk of the electricity output (some 87% in 1950) of decentral town systems.

Table 7.1: Decentral, town based electricity supply systems in number and output 1923-1970.[1]

		1923/24	1931/32	1939/40	1950/51	1960/61	1970/71
Local systems:	n	71	76	70	62	10	0
	GWh	19	26	35	42	5	0
District systems:	n	31	33	34	33	15	8
	GWh	159	145	238	273	160	260
Total:	**n**	**102**	**109**	**104**	**95**	**25**	**8**
	GWh	**178**	**171**	**273**	**315**	**165**	**260**

Together, there were some hundred decentral town systems still by 1950, despite the rapid diffusion of centralized supply first in Eastern Denmark and by now also in Western Denmark. About two-thirds of these decentral town systems was owned by an urban municipality (that is, a municipality of a market-town). This means that the majority of such municipalities still exploited a decentral electricity supply system: Of the about eighty market-towns in Denmark, only thirteen were supplied from elsewhere, while a handful produced electricity in a centralized supply system. The actor group of urban municipalities thus rather homogeneously opted for consolidating decentral electricity supply systems. First in the 1950s and 1960s decentral town systems quickly disappeared: By 1970 all local town systems had vanished, and only eight town-based district systems remained. Five of these had a very small production, so that merely three town systems accounted for about all (96%) decentral electricity production of this group of systems.

This chapter investigates the consolidation of decentral municipal systems at four levels. First, it examines the arguments for decentral municipal electricity production, formulated by spokesmen of the actor group of municipal utilities in opposition to the dominant discourse of centralized supply. Regardless of the 'irrational' arguments pertaining to a 'social' logic, which propagators and historians of centralized supply tended to emphasise, such spokesmen certainly also insisted upon the technical and economic rationality of decentral production. Second, a concrete manifestation of the persistence of the municipal point of view can be found in the preparations of the 1935 Electricity Supply Act. In response to plans to force through centralization from above, the medium and smaller sized municipal utilities managed to act as a homogeneous group in formulating a common stance and successfully mobilizing their arguments in the political process. Partly as a result of this mobilization, the power of decision on the expansion of decentral systems remained with the individual utilities. Third, it addresses the choices at the level of individual utilities through a number of cases. Finally, it examines how municipal utilities massively adopted two technologies to improve the economic performance of decentral town systems: The co-production of heat and power and the use of interconnections in a scheme, which preserved decentral production. It was this latter scheme, that resulted in the construction of the first West-Danish grid in the early 1940s.

A municipal discourse of decentral town systems

The centralization discourse and the irrationality of decentral systems

From the point of view of propagators of large scale electricity supply, there was no doubt that the dispersion of electricity production in Denmark in many relatively small power stations was deeply irrational. The leading discourse, heard in addresses to the Electrotechnical Society and the Danish Society of Engineers, and later also in studies of various government committees, severely criticized the existence of these systems. As we have seen, in his 1917 argument for centralized supply NESA director Angelo spoke of the short-sightedness of small actors causing great national-economic losses. Few years earlier, professor Rung of the polytechnical school had characterized the diffusion of small systems as an 'electrotechnical misère'.[2] This concerned the diffusion of local systems as well as the introduction of district supply systems, many of which were 'too small and have little chance to return their investment'. Even district supply had become 'a matter of fashion', and utilities had built a multitude of small district systems in towns as well as in the countryside. For instance, Rung complained, by 1914 some twelve district systems had been established in Jutland, half of which were town-based systems, and half of which were rural systems. But instead the production of electricity for Jutland should have been concentrated in 'two, perhaps three' large district plants. Likewise, Zealand should be supplied from one plant only. He explained this development by referring to the unfortunate character of 'us Danes', being incapable of taking a large view upon projects, and being too concerned with defending personal and political interests.

The consolidation of decentral systems in an era, where improvements in engines and generators made large scale production ever more attractive, appeared to be increasingly absurd. Two decades later, at a presentation of the 1934 Electricity Bill to the Electrotechnical Society, Rung concluded that the Danes had made the same mistake twice: While they in the first stage of electrification had build far too many small local systems, it was now clear that they had build district systems after the very same principle, a mistake with fatal economic consequences.[3] Just before the Second World War, Holger Hasselbalch-Larsen, chief engineer (and soon director) of the rural utility of North-Western Zealand NVE, described this development as a 'cavalcade of madness'; he condemned particularly the stubborn insistence of both very small and larger utilities to own and expand their own power stations, instead of striving for an optimal concentration of production.[4] The attribution of irrationality to the scheme of decentral supply, then, was an integral aspect of the centralization discourse.

The production of a counter-discourse of decentral production

How, then, was decentral production and expansion justified at the level of debate, after centralized supply had become the dominant paradigm in circles of leading engineers and government? Sometimes, centralisation was indeed rejected in a rather unreflected way, which seems to support accusations of 'local patriotism.' An often cited example is a statement of the Mayor of the Eastern Jutland town Horsens, who during negotiations on a Mid-Jutland co-operation in 1939 rejected to receive electricity from Århus 'even if it was offered for free.' This rejection has been related to the competition between the two towns, not in the least on harbour facilities.[5] Another example is the rather exaggerated fear of Member of Parliament Knud Hansen, who in the journal of the association of market-towns in 1933 pictured a true doomsday scheme, according to which 'international high finance' was about to take over the West-Danish electricity supply business. Municipal systems were to be removed, and electricity mainly imported from Norway, Sweden and Germany. According to Hansen this development had already taken place in East Denmark, where the limited company NESA used a network of high voltage lines - 'big suction pipes'- and local co-operative societies to suck out money from the area. But such arguments only represent the 'overdrive' of an emerging discourse against centralization, and were too far out to be taken serious by municipal actors with similar interests. For instance, although Hansen's warning was published, the editors of the journal reminded the readers (and Hansen) that no municipalities in Eastern Denmark were dependent on 'high finance', and that for instance the Copenhagen municipality was the principal producer of electricity in the East-Danish centralized system.[6]

Instead, there was a more important body of well-informed arguments for the consolidation of decentral town production systems, particularly developed during the 1920s in opposition to the different proposals to establish a national centralized supply system. These arguments soon developed to a veritable discourse of decentral municipal electricity production, which was fostered in particular in municipal organisations, and which was mobilized in all kind of situations, from Parliamentary debates to individual negotiations for instance between utilities and the Electricity Council.

A central character in the first formulation of a general critique of the idea of centralized supply was E. W. Buemann, the plant manager of the town-based district system in Kolding in South-Eastern Jutland. Buemann's arguments had probably, as one observer put it, been shaped over many years of negotiation with his town council.[7] Thus they reflected not only a single man's ideas, but represented a broader municipal interest. In any case, Buemann shaped these arguments into a general critique of the centralization scheme presented by the committee under the Danish association of utilities DEF in 1926, and presented his view the following years to fora such as the general meetings of the association of market-towns [*Den danske Købstadforening*], its subsidiary association of municipal utilities [*Foreningen af købstadkommunale Elektricitetsværker*, founded in 1925] and the Jutland section of the Electrotechnical Society.[8]

Buemann's arguments were primarily economical. As he concluded few years later, centralized supply 'cannot be massively introduced without large economic losses for the Danish municipal utilities', as 'I, among many others, have maintained in our organisations for several years.'[9] As an overall cause that centralization was not economically feasible in Denmark, Buemann pointed at the lack of very cheap production sites such as large waterfalls, hardcoal mines or lignite mines, which made the concentration of production in large power plants situated at those sites so attractive abroad. In Denmark, centralized supply systems would not be able to produce such excessively low cost electricity, and the economic advantages were much more modest. As a result, it would not be economically feasible for Danish municipalities to abandon decentral production. Not only had the latter bound capital in their electricity supply systems, which still had to yield interest and repayment. Also the relatively large expenses of interconnections would overshadow possible advantages of large scale production. For instance, while Angelo in the late 1920s emphasised the economical advantage of sharing common back-up capacity on the East-Danish grid, Buemann responded that it would be cheaper and thus 'rational' for two utilities to each invest in a new turbogenerator for back-up than to purchase one back-up unit and a high capacity interconnection. Finally, Buemann emphasised that centralized supply would entail significant transformer losses at both ends of the interconnections, and large conversion losses at the receiving end if the purchased high voltage, alternating current had to be converted to low voltage, direct current for distribution.

In addition, Buemann mobilized a more specific local argument in the form of the 'significant business interests' tied up with consolidating electricity production in the single municipality.[10] This did not only refer to direct gains in the form of profits for the municipal treasury, which as we have seen was a major reason for Danish municipalities to engage in electricity production in the first place. In addition, he considered it a central concern for a town municipality to 'create as much employment and attract as much local industry and firms as possible.' Electricity production both gave direct employment and thus income to a number of employees, and indirect income through the engagement of local handicraft, trade and service, including for instance use of the local harbour for transport of fuel and machinery transport. An abandonment of municipal electricity production, he estimated (probably for his own town of Kolding), might reduce the capital circulating in a town with one or two hundred thousand krones annually.

The municipal discourse of decentral supply in the 1930s

A second wave of discussions on the issue of centralised electricity supply followed to the second (1933) report of the government committee under the Ministry of Public Works, which recommended a forced centralisation implemented by law. We may take as an example a text of Peder Kjær Bolet, the plant manager and member of the municipal council of Brønderslev in Northern Jutland, in the journal of the association of market-towns.[11] Also Bolet rejected the overall economic gains of centralized supply in a concrete critique of the first (1929) report of the government committee, which had calculated the 'unambiguous national economic gains' of a national centralized supply system and thereby provided the basis for the suggestion of State intervention. For instance, the calculations seriously overestimated the investment and the running cost of the decentralized supply scenario, as could be seen in the actual balances of the urban utilities. At a more general level, he repeated Buemann's argument of the lack of natural resources in Denmark, and added the lack of large industrial centres and a high average electricity consumption per inhabitant, which also helped to make centralized supply feasible abroad. And also Bolet argued that the savings following economies of scale were counter-balanced by the huge expenses of high capacity interconnections and transmission systems, while savings in running expenses were counter-balanced by losses in the new transmission and conversion stations.

Finally, with address to the municipal economy Bolet found accusations that municipalities merely maintained decentral supply systems as local 'toys' misplaced; electricity sales were about '... the only relief for the municipal budgets, which are stretched to the breaking point.[12] Consequently, it was only natural that municipal councils were reluctant to give up self determination over this business. Instead, he reversed the critique and accused propagators of centralized supply for economically irrational behaviour. Thus, he attributed the fascination of these propagators - a few leading engineers, a few representatives of large utilities which would profit from centralized supply, and few national politicians - for centralized supply to a desire to imitate a foreign modernity: "As neighbours sometimes say, 'such a thing we also want'."[13] He suggested that these actors, if so convinced of the economic benefits of centralized supply, would build a power grid with their own money instead of speculating with that of the tax payers.

In the following years, such arguments were frequently heard in general debates concerning the issue of centralized versus decentralized production of electricity. Moreover, they were supplemented by mobilized examples of individual town utilities. For instance, director Sigvard Jensen of the town-based utility of Odder South of Århus added to the debate that decentral systems might have very low production prices, and that his own utility had about the lowest electricity prices in the country. In addition, he observed the 'salesman-mentality' of the large utilities, which merely pursued centralized supply to extend their markets. Their strategy was clearly visible in cases, where small utilities first had to build their own power stations, before the large utility could be convinced to offer reasonable electricity prices.[14] In addition, others might add some new arguments. For instance, Plant manager Olaf J. Westergaard of the municipal utility in Randers emphasised that decentral expansions would create Danish employment: While the introduction of centralized supply for instance meant the import of and thus the 'sending money abroad' for convertors, his utility had recently expanded its decentral diesel power station with a Danish built diesel engine and Danish built generators for one million krones. Of this machinery, only a value of one hundred and fifty thousand krones had been imported in raw material; the rest had been spent in the country in wages and profits, which 'roughly can feed two hundred families or one thousand mouths for a year.'[15] Moreover, each year the engines were kept running would mean bread for Danish citizens. According to Westergaard, such arguments represented the other side of the coin of national economy, which agitators for centralized supply neglected.

As this discussion illustrates, local plant managers played an important role in producing and consolidating a discourse of decentral production. Yet they might also be annoyed by some of the arguments, not in the least the argument of 'business interest' for the municipalities, which implied higher electricity prices than strictly necessary. For instance, plant manager Westergaard complained that the municipalities not only used the net surplus of electricity supply in the municipal budget, but indeed had a range of strategies to squeeze money out of their utility. For instance, there were examples of municipalities using the electricity business to compensate for losses following large municipal construction projects, while others overcharged their municipalities for interest rates on municipal loans to expand the system and thereby scored a profit for the municipal treasury. Alternatively, when lacking means to establish a new school or hospital, the municipality might simply choose to empty the innovation fund of the utility. In other cases fees were charged for municipal administration, while another trick was to write up the value of the system, so that the utility would pay artificial interests and repayment to the city treasurer.[16] Such events caused internal friction between plant managers and municipal electricity committees, as the former were concerned with the performance and service of the utility, while the latter were concerned with the municipal economy at large.[17]

Municipalities and the politics of electricity supply

This discourse of decentralized supply, produced in municipal organisations and journals, influenced the actual developments in the electricity supply field in at least two ways. On one hand, it was a frame of reference for decisions of single municipalities wether to continue decentral production, or to comply with a centralization scheme. And on the other hand, it coincided with and reinforced the mobilization of opposition against the centralization plans in the preparation of the 1935 Electricity Supply Act. In this latter event, smaller and medium sized municipalities directly influenced the political process, and thereby ensured their autonomy of decision on matters of decentral expansions. Such influence was possible, of course, because the Danish political system had developed a tradition of including interest organisations in the decision process. With regard to legislation on electricity supply, the Minister of Public Works had included representatives of interest organisations in the committee preparing the 1907 Electricity Supply Act. And in the mid 1920s the Ministry accepted an arrangement, in which six different interest organisations - including the Danish association of utilities - were to be heard before any changes in legislation or regulation. In 1930 this arrangement was strengthened with the establishment of a permanent committee representing these interest organisations, which was to advise the Ministry on principal questions concerning legislation on electricity supply.[18]

Thus, while the reports of the government committee calling for an the Electricity Council with the competence to deny decentral expansion projects in principle was kept secret from the wider public, it was presented to these interest organisations, which were given the opportunity to respond. The members of the Danish association of utilities, however, did not have a univocal stance towards the report. Larger utilities, some of which had been involved in the work of the government committee, tended to support its suggestions to stimulate centralization through legislation. So did the executive committee of the Danish association of utilities, which proposed to formulate a resolution supporting the idea of an Electricity Council during the annual meeting of the association in 1933.[19] Yet several representatives of municipal utilities were surprised by and displeased with this move. They complained that had not been given prior notice, and had not been able to discuss the matter before the vote. Moreover, they accused the executive board of attempting to 'smuggle in' the resolution of accept as part of the annual report of the association's activities by its chairman, so that an acceptance of this report implied an acceptance of the resolution. They demanded that the issue was taken up for a separate ballot. The resolution was then accepted, but with a considerable opposition: 146 representatives voted for the resolution, 86 against and 15 refrained from voting.

Dissatisfied with this result and the character of the decision process, the issue of forced centralization was subsequently raised within the association of municipal utilities in order to determine a purely municipal stance. And contrary to the Danish association of utilities, the latter association rejected a proposed resolution accepting the decisive power of the future Electricity Council. Another ballot also rejected a resolution, which would not accept legislation at all. Finally, in a third ballot the association accepted a resolution, which expressed agreement with some central control with construction projects expanding outside the natural supply area of the utility involved (56 in favour, none against, 16 refrained). But with regard to expansion of isolated decentral systems, government interference was implicitly discouraged.

Shortly after, but prior to the presentation of the Electricity Supply Bill, the municipal arguments were also presented to Parliament directly during the national budget debates in late 1933. In reply to editor Kay Emun Rager's urge to the government to hurry up with legislation on electricity supply, the above mentioned Knud Hansen explicated the municipal point of view: He warned Parliament against reduction of the municipal right of self-determination and presented the municipal arguments, including doubt on the overall economic feasibility of centralized supply due to the high expenses of interconnections, and the unemployment following after the dismantling of municipal power production.

Indeed, the Minister of Public Works took account of this opposition in his formulation of the Bill, which largely followed the recommendation of the association of municipal utilities: The new Electricity Council would not have decisive power with regard to systems not expanding beyond their own supply area (see chapter five). During the treatment of the Bill in Parliament, the liberal party Venstre strongly backed up the municipal point of view, and after some reformulations the 1935 Electricity Supply Act only gave the new Electricity Council the power of obligatory economic consultant with regard to decentral expansions, and in addition it should be constituted by representatives of the different groups of utilities in order to avoid the dominance of one actor group over the others. In the end, the many decentral Danish utilities thus largely maintained their decision power, and only the construction of interconnection demanded central approval.

Cases: The economy of decentral expansion from the 1920s to the 1950s

Decentral expansion of in the late 1920s: Fredericia and Nykøbing Falster

How, then, did individual municipal utilities argue for the expansion of their decentral town systems? In particular in Western Denmark, which largely lacked a power grid, the purchase of electricity from a larger scale system might simply not be considered as a serious option even by the late 1920s. An example is the decision on an expansion of the power station of the municipal utility of Fredericia in South-Eastern Jutland in 1928. The reason for this expansion, the local plant manager stated before the municipal council, was the increasing demand for electricity; without an expansion of the production capacity, he would not take responsibility for the reliability of electricity supply during the coming winter. Following his calculations of the costs of the expansion and the recommendation from the municipal electricity committee, the council decided to expand with a new (two megawatts) diesel engine.[20]

In Eastern Denmark, by contrast, the issue of electricity purchase from a larger system was much more persistent, as a power grid covering most of the region. In the case of the expansion of the power station in Nykøbing on Falster with a new (seven hundred kilowatts) diesel engine also in 1928, connection to this power grid was seriously investigated, not in the least because the neighbouring rural district utility of Falster had recently joined the East-Danish centralized supply system.[21] Like in Fredericia, the need for an extension of the supply capacity in Nykøbing followed a rapidly increase in electricity demand; currently, the municipal utility had insufficient capacity to supply electricity for new household applications such as electric heating and cooking. This was particularly unfortunate, as the utility considered the supply of such applications as 'a good business', because it would smooth out the load curve. The municipal electricity committee therefore engaged several engineers for advise on the most economical option to extend the supply capacity. However, these proved to disagree, so the recommendation of the available electrotechnical expertise was found inconclusive. The committee therefore investigated the matter itself, and decided to recommend the municipal council to chose for a decentral expansion of production capacity. Its arguments were similar to those heard in the national discussions: On one hand, the committee had compared the annual expenses in the two supply schemes of purchase and increased decentral production of electricity, and found 'decisive advantages' for decentral expansion. In a further report to the municipal council, the committee emphasised that a local consultant had estimated that even if connection to the East-Danish grid gave slightly cheaper electricity, this happened at the expense of sacking a couple of employees, a measure that the committee eschewed. And on the other hand, it stressed the importance of a decentral expansion for local handicraft and commerce. For instance, it recommended that the new diesel engine was ordered at the local diesel engine factory.

On request of the municipal council, also the local plant manager Poul Bützow was asked to comment on the issue. Representing the 'technical point of view', Bützow added that electricity transport on the grid over a great distance included considerable risk for break-downs. To be able to maintain supply in such situations, the utility had to invest in a rather expensive accumulator. In addition, he stressed that the utility would not merely have to purchase electricity, which was available for comparatively low prices in the centralized system, but that it would have to pay a rather large fee for the capacity it occupied at the power station of the supplying utility. Asked directly by a council member for a verdict, he answered that possible modest gains of co-operation would not outweigh the decreased security of supply. Like in Fredericia, the plant manager thus had an important say, and decentral expansion was now univocally accepted by the municipal council. When plant manager Bützow evaluated this decision in the early 1930s, he contended that 'until now time has proven the electricity committee right, for it can hardly be denied that money is better spent to wages within a municipalities own borders, than to purchase of electricity from another town or another country.'[22]

The economic feasibility of decentral production in the late 1930s: The assessments of the Electricity Council

During the 1930s and 1940s, an increasing number of municipal utilities might develop some form of co-operation with other utilities. However, most of them used this option only to exchange additional energy in order to avoid or postpone an expansion of the decentral production machinery, while they kept the existing machinery running. Moreover, a considerable number of municipal utilities actually expanded their decentral production capacity, and decentral production of electricity remained the primary choice of most municipal utilities.

In the case of such extensions of production capacity, from 1935 the utilities were obliged to let the new Electricity Council assess the different supply options in a so-called 'technical-economic investigation.' Such investigations did not consider municipal economic arguments, but only compared the investment costs and the annual fixed and running costs of decentral expansion and of purchase. Therefore, they provide an instructive source to investigate the economic consequences of decentral or centralized supply, on which propagators of centralized and decentral supply disagreed: Would the high costs of transmission lines outweigh possible savings in the production of electricity in concrete cases? According to a list of the expansions of production capacity carried out in 1937-39, sixteen town utilities had applied for expansion. Of these, eleven utilities had the possibility to purchase electricity from a much larger system instead.[23] The decentral expansion plans of four of these were immediately approved by the Council. In addition, the decentral expansion of two utilities was approved after further negotiations; in such cases, the Electricity Council for instance urged the larger utility to decrease its electricity prices in an attempt to make electricity purchase economically attractive for the smaller utility. And a seventh utility, the utility based in Odder, followed the recommendation of the Council to both expand decentrally and establish an interconnection. In sum, only four town utilities insisted upon decentral expansion despite the Council's advise of electricity purchase from a larger system.

The large majority of decentral expansion plans was thus found economically rational by the Electricity Council. This included for instance the immediate approval of expansion of the local system in Holbæk and the district system in Assens, although both market-towns were situated within the reach of large scale systems: The Holbæk system was situated centrally in the supply area of the rural district utility NVE on the East-Danish power grid, and the Assens system on Funen had in fact already been connected to the much larger power station in Odense (which, with a capacity of twenty-five megawatts, was more than forty times as large as the Assens power plant). With regard to the four remaining systems, these might include local economic arguments in their decision for decentral expansion, which the Electricity Council excluded. Notably, in the same period only four town utilities had voluntarily chosen to extend their supply capacity with convertors for purchasing extra electricity fro a larger system. There is no doubt, then, that the municipalities and their utilities massively preferred decentral production.[24]

Decentral expansion in the second half of the 1940s: Skagen and Sorø

Even after the Second World War, the Electricity Council might agree that the expansion of the decentral production capacity was cheaper than the expansion of the supply capacity through electricity purchase. This includes the municipal local system in Skagen in the very North of Northern Jutland, which doubled the diesel generating capacity of its small power station from four to eight hundred kilowatts in 1948. According to its consulting engineer, Stenild Hjort of the P. A. Pedersen firm (who had succeeded Pedersen as its director), decentral expansion would be cheaper both with regard to investment costs and in terms of annual expenses than electricity purchase from the larger municipal utility of Hjørring. An important reason was that this demanded nearly fifty kilometres of new transmission line. The Electricity Council largely agreed to Hjort's calculations, although it contested parts of it (for instance the interest rates on investment), and it warned the Skagen utility that a more detailed investigation 'beyond doubt' would favour a change to supply with purchased alternating current.[25] Under all circumstances, also in this case the municipality mobilized 'rational' economic concerns without particular local interests to the advantage for decentral expansion.

The Skagen case is special, however, as the isolated situation of the town made large scale supply particularly expensive. This was not so for the municipal local system in the small Zealand town of Sorø, which already in the early 1930s had connected to the district system of its much larger neighbour town of Slagelse in order to purchase additional power. Moreover, both towns were placed in a region surrounded by the East-Danish centralized system (figure 7.1). Still, when a small (fifty kilowatts) unit broke down, the municipality decided to expanded its small (400 kW) power station with a diesel unit (160 kW) in 1948. In fact the municipality did not consult the Electricity Council and thus violated the 1935 supply act, for which it was severely criticised. But the electricity council did make a technical-economic investigation, which did prove the decentral expansion to be rational: Despite higher investment costs, the annual expenses in a scheme of decentral expansion would be lower than those in a scheme of increased electricity purchase from the larger steam power plant (3 MW) in Slagelse (table 7.1).[26] With the high coal prices few years after the war, the production of electricity in small diesel engines could be cheaper than the purchase of electricity produced in large steam turbines even on a relatively short transmission line.

Table 7.1: The Electricity Council's comparison of the annual costs of decentral expansion and increased electricity purchase for the Sorø municipal utility (1947).

	Scheme 1: Decentral expansion with a 160 kW diesel engine	**Scheme 2: Increased purchase from Slagelse through a 160 kW converter**
Annual electricity and capacity demand:	1.5 GWh, 550 kW	Idem.
Own production:	1.3 GWh	1.0 GWh
Annual purchase:	0.2 GWh, 150 kW	0.5 GWh, 300 kW
Annual purchase incl. conversion losses (14%):	0.228 GWh	0.57 GWh
<u>Purchase of electricity (2.5 øre pr. kWh):</u>		
Electricity purchase:	5.700 DKK	14.200 DKK
Hardcoal fee:*	12.500 DKK	31.000 DKK
Capacity fee:**	5.800 DKK	10.600 DKK
Transmission fee:***	3.300 DKK	6.600 DKK
Basic fee:	6.000 DKK	6.000 DKK
Subtotal:	33.300 DKK	68.400 DKK
<u>Decentral production:</u>		
Fuel:	55.200 DKK	42.600 DKK
Lubricating oil:	5.200 DKK	4.000 DKK
Higher interest & repayment:	6.400 DKK	-
Higher maintenance & insurance:	1.300 DKK	-
Total annual expenses:	**101.400 DKK**	**115.000 DKK**

*The Slagelse utility charged a hardcoal fee (to compensate for the high coal prices) of 5.46 øre/kWh, which would decrease with decreasing coal prices.

** The Slagelse utility charged a capacity fee (to cover the costs of the used production capacity) of 42 DKK/kW for the first 100 kW, and 32 DKK/kW for the rest.

*** The Slagelse utility charged a transmission fee (to cover the expenses of transmission) of 22 DKK/kW.

Source: Elektricitetsrådet, *Redegørelse vedrørende en teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af Sorø kommunale elektricitetsværk* Feb. 25 1947. National Archives, Elektricitetsrådet, Samarbejdsager, nr. 299.

Decentral production and expansion in the 1950s: The case of Frederikshavn

Finally, during the 1950s the decentral production of electricity in town systems rapidly decreased. Still, several municipal utilities maintained a significant decentral production, even though they might have access to electricity produced in very large power stations through a power grid. Moreover, incidentally decentral production capacity was even increased, even though the municipal discourse was changing to the advantage of centralized supply (see chapter nine). An important group of municipal utilities maintaining decentral production were those in Northern Jutland above the Limfjorden. Consequently, this region was the last large region in the country to fully accept centralized supply, even though in the early 1950s most larger utilities in the area joined forces in a partnership [*Nordjyllands Elektricitets FOrsyning*, NEFO, 1951] to exploit a common sixty kilovolts power grid. Thereby they could purchase additional electricity from the only very large power station within reach, that of the municipal utility of Ålborg. But the electricity prices of the Ålborg utility were comparatively high, which for instance led the municipalities of Brønderslev and Hjørring to order their utilities to produce as much electricity decentrally as possible - despite the new grid.[27] Their decentral power stations were not expanded anymore, however, and although they still had a significant decentral electricity production in 1960, they purchased most of their energy from Ålborg.[28]

The case of the municipal utility of the Northern Jutland market-town of Frederikshavn, by contrast, provides an exceptional but instructive example of the feasibility of decentral expansion even in the 1950s. Although the municipal council had discussed the option of purchasing electricity from Hjørring since the early 1920s, and had participated in the negotiations on supply from Ålborg from 1945, it decided for no less than five decentral expansions of the production capacity of its isolated local system in the 1930s and 1940s. And when it decided on the introduction of high voltage, alternating current supply in the late 1940s, it expanded its decentral production capacity for a sixth time. Finally, instead of integrating the new district system in the Northern Jutland power grid, the municipal council decided to establish an entirely new decentral power station, which was operational in 1950, and to expand this station again in 1953.

Before the 1950s, the municipal council of Frederikshavn had motivated the decentral expansions by their economic feasibility relative to electricity purchase. Even during the first years of the Second World War, when most isolated municipal systems in West Denmark were interconnected (see below), it argued that the construction of an interconnection to the Hjørring power station would doubtless be more expensive, more complicated and more time consuming than its alternative solution: To adapt its own production machinery to be fuelled by natural gas, and later purchase two wind turbines for additional electricity production.[29] First from

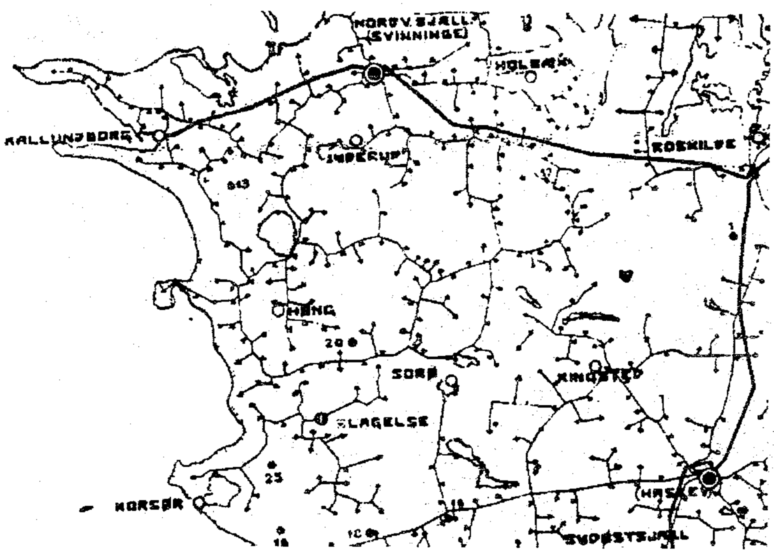


Figure 7.1a: Sorø situated between the transmission networks of NVE to the north, Slagelse to the West and SEAS to the south-east in 1929. Notably, the SEAS grid is not connected to the Sorø system, although it comes very close. Elektricitetsrådet 1957, inserted between pp. 52-53.

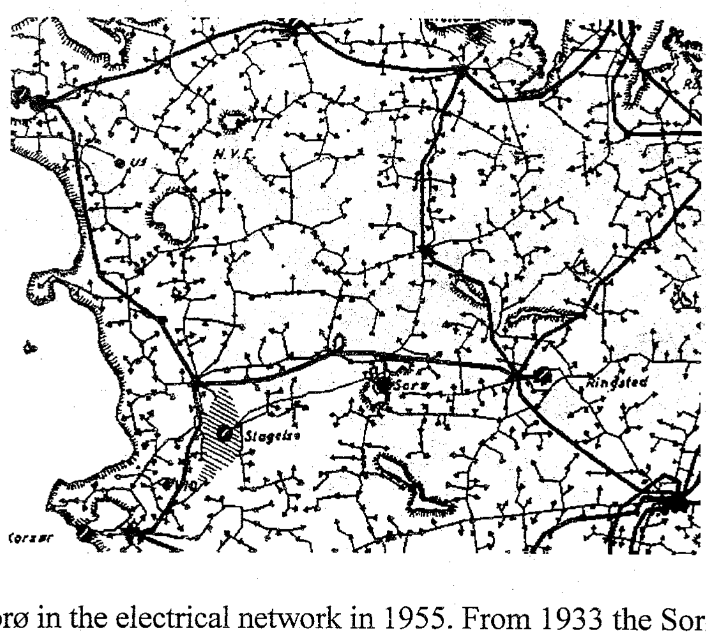


Figure 7.1b: Sorø in the electrical network in 1955. From 1933 the Sorø system had been interconnected with Slagelse, but first in 1953 it would decide for centralized supply, and increasingly purchased electricity through a connection to the NVE network. In 1958 its power station was shut down. Source: Elektricitetsrådet 1957, inserted between pp. 78-79.

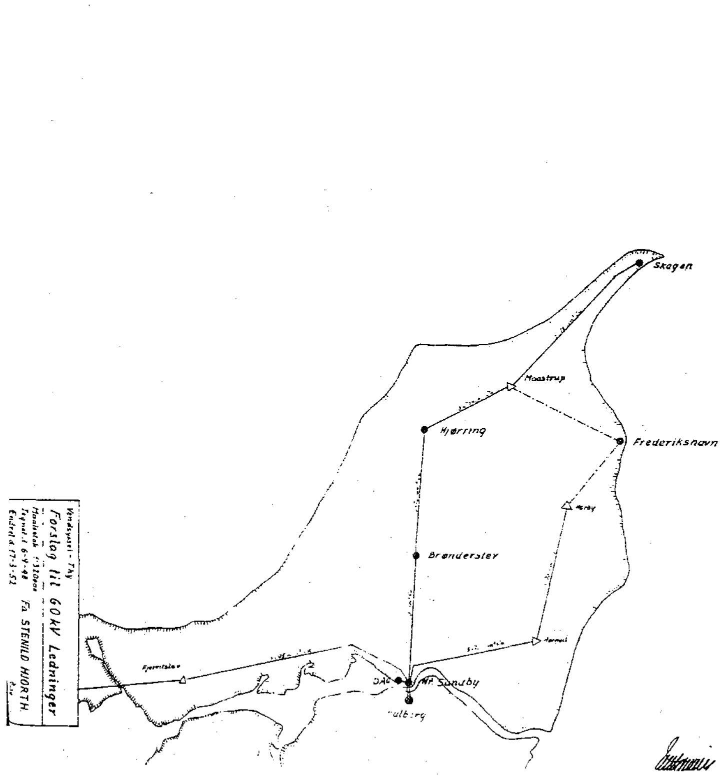


Figure 7.2a: A scheme for the interconnection of Frederikshavn into the Northern Jutland 60 kV grid, designed in 1952 by consulting engineer Stenild Hjort. The grid had by then reached sixteen kilometres south and twenty-four kilometres west of the town. Source: National Archives, Elektricitetsrådet, Samarbejdudvalg, nr. 285.

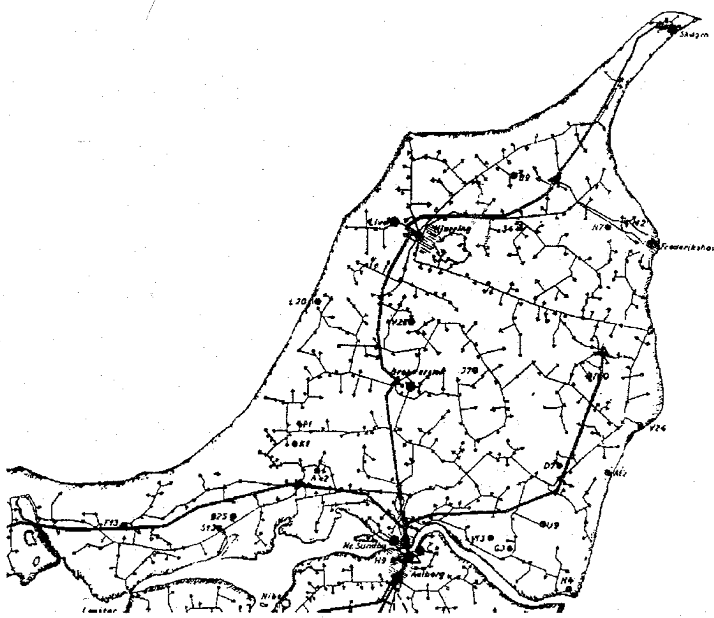


Figure 7.2b: Still in 1955, the Frederikshavn system was not interconnected into the

1950 the complete isolation of the system ceased, as the municipal utility started to buy small amounts of night current from Hjørring through a low capacity transmission link.

What, then, caused the municipal utility of Frederikshavn to double the decentral production capacity of its new power station with a 2.4 MW diesel engine as late as 1953, when the Ålborg utility exploited a power station ten times as large (51 MW), and the Northern Jutland power grid was only sixteen kilometres away to the South and twenty-five to the West (figure 7.2)? In its obligatory dialogue with the Electricity Council, the municipality stressed two leading motives. The first concerned the economy of expansion. An internal report, written by two members of the municipal electricity committee, showed that the annual costs of the decentral expansion scheme would be lower than those of the purchase scheme, even though the initial investment costs of decentral expansion would be significantly higher (table 7.2). The feasibility of decentral production thus followed the estimate, that - with current oil prices - the fuel costs of decentral electricity production (7.3 øre/kWh) were much lower than those in Ålborg (15 øre/kWh in 1952, expected to decrease to 11 øre/kWh by 1962), while a transport loss of about ten percent would further decrease the economy of the purchase scheme.

In view of this result, which reflected the comparatively high electricity prices demanded by the Ålborg municipality, it was safe to assume that local expansion certainly would not be more expensive than interconnection to the sixty kilovolts grid and electricity purchase from Ålborg. Given this economic assessment, the a second and decisive motive was that one of the largest customers of the utility - the military - preferred the large decentral expansion in order to assure an optimal security of supply.[30]

In this case, however, the Electricity Council contested both motives, also after a further discussion with the parties involved.[31] With regard to economy, it argued that the high investment sum of decentral expansion would disable future investments in for instance a common power station. Moreover, it contended that the high annual expenses in the purchase scheme might be decreased, if the Frederikshavn municipality joined the NEFO partnership, so that the Northern Jutland utilities could collectively press the Ålborg municipality to lower its electricity prices. It is noteworthy, then, that, the Electricity Council did not reject the internal calculations. Moreover, in direct negotiations representatives of the Council admitted that they recommended the purchase scheme, as they feared that the nearby municipalities in Hjørring and Brønderslev might follow this bad example and also expand their production capacity.

With regard to the security of supply, the Electricity Council argued that although it was incompetent in military matters, from a technical point of view a supply

Table 7.2: A comparison of the costs of decentral expansion and electricity purchase in Frederikshavn, presented by the electricity committee of the municipal council in 1952.

Decentral expansion:		**Purchase from Ålborg:**	
Investments:			
Diesel engine (3250 hp):	1.560.000 DKK	Share of the Northern Jutland power grid (60 kV):	770.000 DKK
Generator (10 kV):	640.000 DKK	Transformer station (6 MVA):	635.000 DKK
Construction costs:	435.000 DKK	Other:	495.000 DKK
Other:	365.000 DKK		
Total:	3.000.000 DKK	Total:	1.900.000 DKK
Accumulated expenses 1953-62:			
Interest & repayment:	2.600.000 DKK	Interest & Repayment:	1.750.000 DKK
Fuel:	3.464.000 DKK	Electricity/capacity purchase:	5.889.000 DKK
Other:	625.000 DKK	Other:	630.000 DKK
Total:	**6.689.000 DKK**	**Total:**	**8.269.000 DKK**

Source: Gudmund Nielsen & W. Hanning, *Kalkulation over anlægsudgifter samt årlige driftsudgifter ved udvidelse af Frederikshavn elforsyning, 27. marts 1952.* National archives, Elektricitetsrådet (1404), samarbejdudvalget, nr. 285.

system based upon a single large diesel engine was particularly vulnerable; the most reliable supply would be obtained through connection to the grid, which interconnected a number of power stations. In addition, the military could maintain a local back-up system of its own. However, the representative of the military in the negotiations rejected this argument. On one hand, a military back-up unit would be insufficient, as wartime supply not only involved military installations, but also civil applications as cranes, the water works, lighting etc, which demanded a large power station as that of the Frederikshavn municipality.[32] And on the other hand, in time of a military crisis supply from Ålborg would be particularly vulnerable, as (1) a long transmission line between Ålborg and Frederikshavn was difficult to guard against sabotage, (2) a large power station as that of Ålborg would be a primary target in an airborne war, (3) due to its size and large staff it was also comparatively easily sabotaged from within, and (4) in the hypothetical situation that Danish troops were pressed North of the Limfjorden, it would be rather inconvenient to depend upon a power station on the Southern bank of the fjord. Full production capacity in Frederikshavn did not have these disadvantages; moreover, Frederikshavn was under the umbrella-protection of the local artillery units, while fuel oil would be locally available even in wartime, as supply of the local naval base in Frederikshavn had high national priority.

In addition, he stressed that the military in general was displeased with the centralization movement in Danish electricity supply, as it found that the concentration of production in few plants generally decreased the reliability in wartime situations. But while it could accept this situation elsewhere in the country, Frederikshavn was of particular strategic importance because of its naval base. Moreover, NATO current negotiated on a NATO navy base in Denmark, which could suitably be situated in Frederikshavn, so that convoys from Norway and England would not have to penetrate very deep into Danish waters. Finally, with regard to the issue of economy the military representative argued that the extra investment costs of decentral expansion, of about one million krones, could easily be written off through the military consumption alone at a reasonable electricity price.[33]

Although several members of the Electricity Council did not accept these arguments either, they decided to continue negotiations only with the utility representatives. These, however, insisted upon their calculations showing the advantage of decentral expansion, and stressed that the municipal council wished a good relation to the military, which was so massively engaged in the town.[34] The expansion, therefore, was carried through. Only in 1957 the Frederikshavn municipal utility joined the Northern Jutland partnership and thereby the centralized system of a 60 kV power grid fed by electricity from Ålborg. Still, by 1960 it only used this link only to purchase part of its energy, while it kept its own engines running more than five thousand hours annually (or sixty percent of the time), locally producing some eight gigawatthours or forty percent of its electricity demand.[35] The decentral power stations in Frederikshavn were first closed after 1967, when the NEFO partnership inaugurated its own very large power plant, the feasibility of which presupposed that the partners shut down their decentral plants.[36]

Improving the economy of decentral production: Combined heat and power production

While the above examples show that the municipalities justified their consolidation of decentral electricity production in terms of their economic feasibility, in other cases they actively improved the feasibility of their systems through technological innovations. One innovation, that was particularly important in the decade after the Second World War, was the combined production of electricity and heat, so that the heat could be sold commercially to the public and provided extra income for the utility (and thus the municipality).

Commercial town heating had been started in the late 1870s and 1880s in the

United States, where pure heat plants produced steam in a boiler and distributed it to consumers through an underground pipe system. Electric utilities soon engaged in this market, however, not in the least to attract consumers which run decentral heat and power systems. Moreover, when the electric utilities build new, larger power plants outside the cities, the old inner city plants could be converted into heat plants, possibly with a combined heat and power production. In Europe, town heating was introduced in Germany in the 1890s, but it only accelerated following the high fuel prices of the First World War. To exploit the energy value of the fuel optimally, heat was primarily produced in electric power stations with a combined heat and power production.[37]

In Denmark, the German model was followed with a small delay. Shortly after the turn of the century, town heating had been taken up on very a modest scale, when the municipalities of Frederiksberg and Copenhagen started to supply heat to public buildings such as public baths, schools and hospitals from their new incinerator plant and electric power plants respectively. Commercial town heating to private customers was first taken up in the second half of the 1920s. In Copenhagen, where electricity production had been concentrated, the boilers of the three old, decentral power stations were now used as town heating stations, although these plants did not combine heat production with power production in the same units until the mid 1930s. In provincial towns, by contrast, town heating was from the beginning at least partly combined with electricity production. For instance, in Århus (1928) heat for commercial town heating was taken from an outlet in the new steam turbines, while in Fåborg (1925), Esbjerg (1927), Randers (1931) and Slagelse (1936) the municipalities decided to take up town heating to exploit the waste heat of their new diesel engines.[38] By the mid 1930s, there were some fourteen electric utilities in Danish towns, which co-produced heat for town heating in their power stations. Two decades later, in 1954, their number had increased to about thirty: Five of these utilities participated in a centralized supply system, while the remaining twenty-five utilities exploited decentral town systems; about half of these were local town systems, the other half town-based district systems. Combined heat and power systems, in sum, made up a significant share of the decentral town systems that remained in the mid 1950s. From then decentral heat and power production lost importance, however: While electricity production was concentrated in few plants, heat supply was often taken over by pure heat plants without electricity production.[39]

The economy argument of CHP

The technology of and economic argument for establishing combined heat and power production was for instance summarized by Niels Christian Geertsen, a leading engineer at the heat department of the Copenhagen municipal utility, at the annual meeting of the association of Danish utilities in 1935.[40] Geertsen distinguished between two technological possibilities for Combined Heat and Power production (CHP production) in electric utilities. First, in case of a diesel engine available in most smaller utilities, the efficiency in normal electricity production was about thirty percent; that is, about thirty percent of the energy value of the diesel oil was converted into electrical energy. The remaining seventy percent were lost as heat, primarily in the cooling water and in the exhaust gases. However, a substantial amount of this lost heat energy could be used productively, if the heated cooling water was used for heating purposes. Furthermore, the exhaust gases could be made to further heat the cooling water in so-called economizers (pipe boilers, where the exhaust gasses were led through the pipes to further heat the water). Producing both electricity and heat, the power plant could raise its energy efficiency to some seventy-five percent. Or, put in another way, heat was available without extra fuel costs: Diesel CHP plants might produce a thousand cal. of heat energy per kilowatt hour of electricity produced. In traditional coke-fired central heating installations in single buildings, the production of this amount of heat would cost about one øre. As the fuel costs of diesel power stations were about two øres per kilowatt hour at the time, CHP production raised the net value of production by fifty percent.

Second, in modern steam power units used in larger utilities, the overall efficiency of electricity production was about twenty-three percent. Due to the low costs of coal per unit of energy, steam power plants were competitive despite energy losses of nearly eighty percent. The main losses were heat losses in the condenser, amounting to about half of the energy value of the hardcoal. To make these heat losses productive, the turbogenerator with condenser could be replaced by a so-called 'back-pressure' turbogenerator: In such units, the high pressure steam from the boilers (at e.g. twenty-five atmospheres) was not reduced to the near vacuum in the condenser, but only to a steam pressure of two or three atmospheres. Under this pressure, the steam could either be directly fed into the pipe system for heat distribution (steam-based town heating), or be used to heat the circulation water in a heat exchanger (water-based town heating). While the heat thus could be used, the increased pressure after the turbine (relative to the near vacuum produced by condensation) did reduce the amount of electrical energy produced up to fifty percent; thus, such CHP units demanded more fuel to produce a similar amount of electricity. Still, in this arrangement, the overall efficiency of the energy conversion process could be raised to some 78%.

The use of waste heat, however, did not automatically make CHP production economically feasible for town utilities. For there were several complications. For instance, the peaks of the electricity and heat demands occurred at different times of the day - the electricity peak often occurred in the late afternoon (when lights were on but engines still running), while the heat peak often occurred in the morning. As a result, part of the heat produced had to be stored in huge and expensive heat accumulators. Moreover, in summertime the heat demand was low and the heat capacity of the plant might be largely unused, while in wintertime demand was high and possibly required extra boilers to produce additional heat. Put together with the investments in CHP machinery, an accumulator and not in the least an expensive pipe system, the feasibility of combined heat and power production depended very much on the specific heat and power demands of the individual town.

For some town utilities with CHP production, the economic advantages played only a small role in the beginning, and supply covered only few - often municipal - consumers, which might receive their heat for free. The municipal utility in Fåborg, for instance, started in 1921 to supply the waste heat from its diesel engine to the public bath. First in 1925 it developed a larger heat supply system, which supplied heat to two nearby schools, the administration building of the utility and later the local church and some private houses.[41] In other cases, as in Randers, an economic investigation showed from the beginning the advantages of commercial heat supply. In this case the issue had been brought up in the early 1930s by the education department of the municipality, which asked the utility if heat supply from the power station was possible and economically feasible instead of an expensive improvement of the heating systems in some schools. The electricity committee of the municipality then investigated the matter, engaged an engineering firm - that of Bruun & Sørensen, which designed most of the heat systems in Danish towns - to calculate its feasibility, and then decided to build a system supplying more than thirty buildings from the beginning. By the early 1940s, the number of consumers had increased to more than two hundred.[42]

CHP and the feasibility of centralized electricity supply

It was only during the Second World War, however, that the issue of CHP production gained importance in discussions on the concentration of electricity production. For instance, director Christian Wegener of the municipal utility of Århus suggested to abandon the schemes of centralised electricity supply, and instead establish CHP plants in the large and medium sized towns with more than twenty-five thousand inhabitants. His argument was national-economic: During the war it was of major importance to save on hardcoal imports, which could be achieved by producing heat in electric power plants instead of the central heating boilers of individual households and firms. Trying to win the Ministry of Trade for this plan, Wegener sent in the economical results of the Århus CHP plant, showing that the production of heat from the power station required only an extra quarter of the fuel, which normally would be used for heat production in private boilers. In this way, the

Århus plant alone annually saved the country for imports of some twenty thousand tons of hardcoal. His view was supported by others, and it was for instance argued that 'millions of krones' could be saved annually by using the waste heat of the electricity plants, although this required that the concentration of electricity production was be sacrificed.[43]

The technical subcommittee of the wartime government commission 'Electricity Commission of 1941' (see chapter five) was set to investigate this matter. In its report, published in 1946, the committee argued that CHP production might be feasible in towns with more than fifteen thousand inhabitants; yet, an arrangement of CHP plants in such middle sized towns would not be economically competitive compared to a scheme of centralized electricity supply. With regard to Western Denmark, where electricity production not yet had been concentrated, the committee suggested to concentrate production in six very large power plants only; if these were situated near large enough towns (such as the existing plants in Århus, Ålborg, Esbjerg and Odense and possibly a new one in Vejle) CHP production in these very large plants would be economically advantageous. The advantages of concentration of production would more than outweigh the advantages of heat sales in a scheme, where smaller CHP plants were maintained (such as the existing plants in Fredericia, Kolding, Vejle, Horsens or Randers).[44] It is noteworthy, however, that the committee was made up by representatives from the largest utilities in the country, which had a vested interest in the concentration of electricity production in their plants (for a more detailed discussion see chapter nine).

As the municipal opposition towards the concentration of production weakened after the Second World War, the combined production of heat and power was never actually embedded in a discourse of decentralized supply. Still, by the mid 1950s director Bak of the Copenhagen utility - a co-author of the 1946 report - suggested that CHP production might be feasible for utilities in provincial towns, which already had made some of the investments costs. This included for instance municipalities, which had idle local power stations, after they had started to by electricity from a centralized system. However, Bak contended, even if all twenty Danish towns larger than fifteen thousand inhabitants would adopt CHP plants, their electricity production as well as their savings on fuel would be insignificant in the national economic picture. The matter was therefore relevant for the local economy only, and the feasibility of decentral CHP production depended upon structure of the town and the value of the decentrally produced electricity, relative to that obtained from the centralised system.[45] The matter was up to the single municipality.

CHP and the consolidation of the large district system of Randers

A large decentral system, which was maintained in the age of centralized supply with reference to its combined heat and power production, was the municipal district system in Randers. Although Randers was one of the larger towns of the country (forty thousand inhabitants in 1950) and its district electricity supply system likewise one of the larger in the country (eighteen megawatts in 1945), it was not included in the centralized supply scheme for West Denmark proposed by the government committee. Instead, the nearby power station in Århus (thirty-four megawatts) should be expanded to cover the Mid-Jutland load in the centralized system. Moreover, the report used the example of Randers to illustrate that a decentral production of electricity would be disadvantageous, even if combined with heat production.[46] However, this exemplary calculation explicitly excluded the already existing CHP system (and thus overestimated the investment costs of the decentral CHP scheme), while it also excluded the construction of an interconnection, as it presupposed that the system in all circumstances would be connected into the West-Danish power grid (and thus underestimated the costs of the centralized supply scheme). In practice, as plant manager Westergaard underlined and also the report acknowledged, the existing CHP system 'undoubtedly' made the Randers system economically feasible.[47]

In fact, like in other towns the heat demand in Randers rapidly increased after the Second World War as new customers desired heat supply (the number of consumers tripled in the second half of the 1940s). Soon the heat business became a central concern of the utility, and expansions of the power plant were partly motivated by the increase in heat sales.[48] Moreover, with reference to the advantageous economy following from CHP production, the Randers municipality gave low priority to interconnection in the West-Danish power grid, even though the 60 kV grid of the Mid-Jutland centralized system was in close range (there were 35 kilometres to Århus and 25 kms to Tange). Until the mid 1950s, therefore, the Randers CHP system remained a large but practically isolated (a low-capacity connection to Århus was not used since the 1920s) town-based district system. As late as 1954, the Electricity Council reluctantly approved of a decentral expansion with a large (twenty megawatts, eight of which for heat production) CHP unit, as it had to admit that the heat sales made this decentral expansion cheaper than interconnection to the West-Danish power grid and power purchase from Århus. As the Randers utility obstructed the extension of the grid up North, some members of the Council expressed regret that they could not 'force' the utility to interconnect. But the Randers municipality chose to postpone the question of interconnection, until the 'economic advantages had grown larger'.[49]

If the Randers system was still interconnected in the grid soon after, this was because the Electricity Council insisted on the continuation of negotiations with representatives from Randers as well as from Ålborg and Århus, the interconnection of which should run via Randers, and because the latter two municipalities complied on giving Randers particularly favourable terms for participating in the grid.[50] Moreover, even though the Randers system was interconnected in the West-Danish power grid, and the power stations in Ålborg and Århus were three to four times as large by 1960 (117 and 180 MW respectively, towards Randers 41 MW), it maintained its decentral electricity production. According to the chairman of the partnership ELSAM running the West Danish centralised system (see chapter nine), it was the CHP production in Randers that was 'the basis for the existence of the power plant.'[51] In fact, the decentral electricity production in Randers increased steadily from 57 GWh in 1950, via 67 GWh in 1960 to 118 GWh in 1970. This was the bulk of the electricity demand in the town, and made the Randers system the largest decentral town system in Denmark.[52] Only in 1971 the Randers municipality actually joined the centralised system, as it became a partner in the partnership *I/S Midtkraft*, which exploited by then two large power stations in and near Århus. Hereafter the majority of the energy was taken from the centralised system, and the size of decentral electricity production in Randers was reduced to an amount, that followed the heat production in back-pressure engines only.[53]

Electricity as a by-product: The consolidation of smaller CHP systems

In addition to this large decentral town system, a number of municipalities maintained much smaller town systems during the 1950s and 1960s because of their CHP production. Contrary to the Randers system, these often purchased the bulk of electricity from the centralized system, but maintained decentral electricity production as a by-product of the local supply of town heating. The largest of such 'smaller' CHP plants was the oldest inner city power plant in Copenhagen, which supplied town heating from CHP units from the 1930s, while the Copenhagen utility concentrated its electricity production in other, much larger power plants. Although a fairly large plant due to the large heat market of the inner city of Copenhagen, by 1970 it accounted only for one percent of the electricity production in Copenhagen power plants. Thus, it had no practical importance for the electricity supply market.[54]

On the other hand, it was much larger than CHP plants maintained in a similar arrangement in provincial towns. When the establishment of a centralised system was negotiated on Funen in the second half of the 1940s, it was agreed that the municipal utilities ceased their decentral production in order to achieve an optimal market for the new large power station built near Odense (and which, incidentally, supplied Odense with town heating). However, the smaller municipalities of Fåborg, Nyborg and Svendborg were excepted from this principle, and were allowed to produce an amount of electricity following the heat production in their CHP plants. The CHP plant in the small market-town of Fåborg (five thousand inhabitants in 1950), for example, retained the right to produce 1.6 GWh electricity annually. This is less than a tenth of the electricity production in the inner city CHP plant in Copenhagen during the 1960s. Yet, the Fåborg system contributed with seven percent to the electricity demand of the municipal utility.[55]

Likewise, the municipality of Slagelse (nineteen thousand inhabitants in 1950) on Zealand - which had co-produced heat for town heating since the mid 1930s - maintained a small electricity production even after it decided to participate in the East-Danish centralised supply system from 1953. The choice between decentral CHP production and electricity purchase from the centralised system had been on the agenda of the municipal council since the end of the Second World War, and it had decided to both increase the capacity of interconnection and expand decentrally with a back-pressure turbine.[56] After the municipality joined the centralised system in 1953, however, the electric utility would purchase its base electricity load; the decentral CHP plant was now turned over to a separate heat utility, which maintained a small (some 3 GWh in the second half of the 1950s) decentral electricity production, which it sold to the electric utility.[57]

Finally, in the case of the Kolding municipality (thirty-one thousand inhabitants in 1950) in South-Eastern Jutland, the municipality decided to take up decentral CHP production *after* it was decided to purchase electricity supply from the centralized system in 1946. Knowing that the decentral electricity production soon would cease, and that the utility's production machinery only retained scrap value while its personnel had to be relocated, the electricity committee investigated several possibilities to 'keep the chimney smoking'. The Århus firm A/S Bruun & Sørensen was engaged to work out a scheme for town heating based on the existing production machinery, and in 1950 the committee proposed a 'economically and technically feasible scheme' to the municipal council, which agreed to the project. Few months after the power station was closed down in 1951, it re-opened as a heat station, originally supplying a 137 buildings (extended to 240 the year after). Like in Slagelse, the new system was run by a new heat utility, which sold the electricity from its CHP units to the electric utility at a price, which equalled the prices of the electricity purchases from the centralised system.[58] As a consequence, it was registered in the electricity supply statistics not under electric utilities but as an autoproducer, and the available figures thus underestimate the number of decentral town CHP systems.[59]

The case of the Kolding plant also illustrates the economy of local CHP production relative of pure heat supply directly from the boilers. The economy of these two methods of providing town heating had been much discussed since the late 1940s, and an increasing number of town utilities preferred town heating from pure heat plants. The Kolding plant used both systems, and in the late 1950s its plant manager could compare the running costs of the old steam powered CHP units with those of the new oil fired heat boilers. In the budget year 1957/58, the plant had nearly run its oil fired boilers. But when the oil prices rose the next year, it again used its steam powered CHP units. While the system produced some 40.000 Gcal of heat in both years, in the first year it produced only 0.3 GWh of electricity, in the second year some 6 GWh. In the latter case the use of primary energy increased with some 20%, but thanks to sale of electricity to the electric utility, the net fuel costs per produced Gcal of heat was 20% lower. Thus, CHP production in heat utilities could well be feasible even with a relatively small electricity production and low electricity prices.[60]

Interconnection and decentral production: The municipal model of decentral co-operation and the first West-Danish grid

Another important issue with regard to the consolidation of decentral town systems was the combination of decentral production with the new technology of (inter)connection. For the engineers and government committees that had argued for centralised supply on a national level, as well as for the Electricity Council, the point of interconnection was exactly to concentrate production. Thus, the reports investigating the advantages of centralized supply used to compare a scenario of interconnected, very large power stations with a scenario of isolated, smaller decentral power stations. And the chairman of the Electricity Council, professor Aubeck, stressed that a consultance body like the Council should not 'barter' the principle of centralisation for that of constructing interconnections, and thus not recommend interconnection unless combined with a concentration of production.[61]

This view upon interconnection as part of centralized supply, however, was not accepted in municipal circles. Indeed, plant manager Buemann had already argued for an arrangement of 'decentral co-operation' in his critique of the centralization paradigm in the 1920s. He insisted upon a sharp distinction between 'centralization' on one hand, and 'common co-operation' between neighbour electric utilities on the other. In Buemann's view, the latter kind of co-operation was acceptable, and would probably also gain the sympathy of the municipalities. The kind of co-operation implying centralization, however, ought to be avoided, partly for economic reasons.[62]

Moreover, several town utilities in fact did combine the technology of connection or interconnection with the consolidation of decentral electricity production already in the 1920s. For instance, since the early 1920s the two small town-based systems of Thisted and Nykøbing Mors and the rural district system of Thy in North-Western

Jutland had connected their transmission grids. The original idea was to provide surplus electricity from the Thisted system to the Morsø system, but in 1926 the arrangement was expanded to an actual co-operation, in which the parties pooled their complementary fuels (coal in the Thisted system and diesel oil in the Morsø and Thy systems), and shared their load in a common load management. But they did not concentrate production; instead, they each expanded their decentral systems regularly.[63] And in Northern Jutland above the Limfjorden, the municipal utilities of Nørresundby and Hjørring had established a modest co-operation on a separate interconnection in 1924. The line had been built for twenty kilovolts, but was operated at only ten kilovolts until 1928. This project of interconnection had been initiated by consulting engineer Svend Aage Faber in 1922; the intention was to concentrate the electricity production in the nearby large power plant of Ålborg, or alternatively in a new, common power station to be built in Nørresundby. But to the regret of Faber and other propagators of centralized supply, the Hjørring municipality decided to build a new decentral diesel power plant just outside the town, which was operational in 1924 (and later expanded in 1939 and in 1951). The interconnection was thereafter used for the co-operation between two decentral power plants only.[64]

A model of decentral co-operation: The South-Eastern Jutland Interconnection

The most debated and influential case of decentral co-operation before the Second World War, however, was beyond doubt the co-operation between the four South-Eastern Jutland towns of Kolding, Fredericia, Vejle and Horsens. From the mid 1930s, these exploited an actual high capacity interconnection of their four town-based district systems, operated at sixty kilovolts. The idea of interconnection of some of these systems had already had been discussed by their plant managers and their common consulting engineer, engineer Stenild Hjort from the P. A. Pedersen firm, in the 1920s. The municipal councils, however, had been sceptical. But the idea was revived in the early 1930s, following a lack of back-up capacity in all four town-based district systems. In 1933 the four municipalities started negotiations on a co-operation, in which they originally planned to use a 25 kV interconnection to share back-up capacity: The four utilities should expand their decentral capacity in turns, and after each expansion, the new engine was to be used for common back-up. It was calculated that this arrangement would save each municipality for some four hundred thousand DKK in machinery over a fifteen years period compared to a scheme, where each municipality should invest in full back-up capacity. For the Horsens municipality, this was about a third of the expected expansion costs in this period.[65]

By negotiating this scheme, the four municipalities rejected the centralisation scheme suggested by the 1929 government report, in which the towns were included in the large Jutland Interconnection from Åbenrå to Århus (or even to Ålborg) at 60 kV, and should cease their decentral electricity production. Instead, they should purchase their electricity from the Århus municipal utility and the Southern Jutland utility. Consequently, propagators of centralized supply fiercely criticised the plan of the four municipalities: The mayor of Århus, for instance, wondered why the four towns wanted exclude his municipality from their co-operation, particular as electricity prices were significantly lower in Århus than in the four smaller towns. He feared that if the Ministry would allow this project to continue, it would break up the large centralisation project in Jutland, 'in which Århus is particularly interested' and 'for which we have worked for years.'[66] In addition, MP Kay Emun Rager took up this concrete case during the 1933 Parliamentary Budget debates; reminding Parliament of the huge economical stakes of the centralisation project calculated in the 1929 government report, he saw the plan as an obstruction: For the establishment of the planned 25 kV interconnection would not make the desired 60 kV power grid feasible for years. He warned the Minister of Public Works that this scheme should be stopped soon, and went as far as to appeal to the farmers in the area to refuse the construction of masts on their land, so as to delay the project until a new Electricity Supply Act had been enacted.[67]

Thus pressed by opposition, the municipal politicians of the four towns publicly motivated their choice for a scheme of interconnection and decentral production. The chairman of the electricity committee of the municipal utility of Kolding maintained in a regional newspaper, that the centralized supply scheme of the government committee would only benefit the utilities in Århus and Åbenrå, which would be the producers and salesmen on the grid. For his own municipality, the arrangement would imply a loss of direct income and a loss of employment of some thirty bread-winners. He acknowledged that electricity might be obtained a little cheaper in the calculated centralization scheme, but after the Kolding power station was dismantled, who would guarantee that the large utilities would not exploit their monopolies and increase electricity prices? Besides, he argued, the construction of the large interconnection from Åbenrå to Århus would be an expensive affair. The four South-Eastern Jutland municipalities therefore preferred a more local co-operation between the four towns only, in which case the advantages of cheaper electricity through co-operation were combined with maintained autonomy for the four utilities.[68] Likewise, a member of the municipal electricity committee of Fredericia doubted that the centralisation scheme would yield a positive economic result, stating that 'we trust more in a smaller co-operation, the economic and other consequences of which we can easily survey.' He also suggested, in reply to the critique by the mayor of Århus, to 'let Århus build itself the projects, in which it has an interest.'[69]

After some one and a half years of negotiations, in 1935 the four municipalities founded the partnership South-Eastern Jutland Interconnection [*I/S Den Sydøstjydske*

Samleskinne] to (1) secure mutual back-up in case of emergencies, (2) exploit the common back-up capacity and thereby postpone extensions of the decentral production capacity, (3) operate the four power stations so as to achieve the optimal common economy and (4) use the advantages of expansion with larger engines in a single power station at the time, instead of several smaller engines in all four power stations. In addition, a crucial element of the agreement was that each partner retained the right to produce as much electricity, as it needed to supply its own supply area. Thereby the municipalities retained the last say in production schemes. Technically, it was decided to build the interconnection for sixty kilovolts instead of twenty-five kilovolts, which eliminated part of the criticism.[70] Still, as the member of the Fredericia electricity committee had put it in 1933, even if the interconnection was build for sixty kilovolts, the East Jutland towns 'have no desire to become part of a larger co-operation.'[71] When the system was operational in 1936, the four municipalities had indeed succeeded in combining interconnection with decentral production in comparatively small power stations: While they operated power stations with a capacity of three or four megawatts in 1940, the Århus and Southern Jutland utilities run power stations about ten times as large (twenty-eight megawatts and thirty-nine megawatts respectively).

During the second half of the 1930s, the arrangement was repeatedly evaluated and compared to the option of additional electricity purchases from larger power plants outside the co-operation. The arguments, however, remained in favour of the 1935 agreement.[72] For instance, following a planned extension of the Horsens power station, the executive committee of the partnership investigated the feasibility of electricity purchase from the large power stations in Esbjerg, Southern Jutland, Århus and Odense. Of these, only the offer of the Southern Jutland utility implied some economical savings, but the committee preferred expansion of the Horsens system with the motivation, that connection to a very large power station might undermine the future independence and expansion of the four town utilities. In 1937 this proposal was accepted by the four respective municipal councils.

The partnership then had to justify this decision towards the Electricity Council, which rejected the economic rationality of a decentral expansion Horsens. The parties discussed three supply schemes: The necessary additional electricity could be purchased from Århus and Southern Jutland, it could be produced decentrally by maintaining the scheme of decentral expansion in turns, or it could be produced in a new, common large power station for the four towns. When the manager of the partnership, Hans Bekkevold, and its consulting engineer, Stenild Hjort, calculated the economy of the different options based upon a concrete offer of the Århus and Southern Jutland utilities, the purchase option was the most expensive, while the other options were about equal. A closer investigation showed that the common power station was cheaper in the long run but more expensive in the short run (see also chapter nine), and in a joint meeting the municipal electricity committees of the four towns insisted upon the principle of decentral expansion. The calculation of the Electricity Council, however, showed the opposite result: The purchase option would save some 150.000 DKK annually. In following negotiations, however, the parties agreed that the differences depended upon a number of uncertain variables, so that a conclusive assessment was impossible.

By then, however, expansion of the production capacity within the interconnection had already been realized, not through an expansion of the Horsens power station, but through the extension of the interconnection up North to the nearby town-based system of Odder. The latter had a surplus capacity of some three megawatts in its newly expanded power station, and by extending the co-operation to the Odder utility, the partnership obtained the necessary back-up capacity in a scheme of decentral co-operation.

The first West-Danish power grid

While few large East-Danish utilities had quickly expanded their originally decentral co-operation into a large centralized supply system covering most of the East-Danish region, in Western Denmark such a system was far from being realized by the eve of the Second World War: The largest utilities had not joined forces and built a system themselves, while the important group of middle-sized municipal utilities had preferred either isolated operation, or interconnection on a smaller scale while maintaining decentral production. However, the War changed the situation at least with regard to the power grid: Within few years, a first West-Danish power grid was finally established, which covered the largest part of the region, excluding only Northern and North-Western Jutland.

Different from Eastern Denmark, the initiative for building this grid did not stem exclusively from the largest utilities, but was a joint project of large and small actors in the region. And for the municipal councils in medium and smaller sized towns, the motive to participate in the grid was not to decrease the costs of supply by concentrating production. Instead, it was plainly to acquire sufficient electricity to keep up supply as much as possible in times of severe fuel shortages. Shortly after Denmark was occupied by Germany in April 1940, import of the two most used power sources - hard coal and diesel oil - was restricted to the Germany dominated areas. While diesel oil imports stopped almost completely, an agreement between the Danish and German governments secured the import of hard coal. In return, Germany was allowed to recruit Danish labour for German factories.[73]

The utilities then negotiated a complex of mutual contracts, specifying the sale and purchase of additional energy and financing of the interconnections. The government participated in these negotiations through the so-called 'electricity committee of 1940', which had the competence to take initiative to and mediate in the negotiations between the utilities. The committee worked on one hand to connect most diesel power stations to steam power stations, and on the other hand to interconnect most steam power stations in a power grid. In this way, the available steam turbines in the area could be optimally used. But according to one participant, the director of the Århus utility, negotiations between the utilities could be 'long and difficult', and the plans were realized only because there was an instant lack of engine power, which smaller utilities could only obtain by co-operation.[74]

Thus forced to co-operate, the West-Danish utilities had constructed a power grid for 60 kV covering most of Western Denmark by 1942. In a first stage, there were three important construction projects (see the dashed lines in figure 5.8). The existing South-Eastern Jutland interconnection (Odder-Horsens-Vejle-Fredericia-Kolding) was extended South to the transmission grid of the Southern Jutland utility and North to Århus; a so-called West-Jutland interconnection was established by extending the local interconnection of the thermal power plant in Esbjerg with the Karlsgaarde hydropower station North to Herning; and on Funen, the Odense power station was interconnected with those of the towns Svendborg and Faaborg.[75] And in a second stage, after a governmental 'fuel board' confiscated remaining oil stocks, several additional lines were build to facilitate additional purchases of the West-Jutland and Funen systems, which lacked capacity, from the Southern Jutland utility. Thus, the Esbjerg power station was interconnected with the Southern Jutland system, while the Odense power station was interconnected with that of Fredericia on the South-East Jutland interconnection.[76] This last interconnection, which completed the grid, was inaugurated in December 1942. The energy flows between the participating utilities were coordinated by a specially established 'committee for steam power stations in Jutland and on Funen', consisting of representatives from the larger and middle-sized municipalities in Western Denmark. In Northern and North-Western Jutland, which were not included in the grid, the Ålborg area was supplied by the Ålborg steam power plant, the Vendsyssel area in the very north by the steam power plant of the co-operative cement factory, while the utilities in the North-West were allowed to burn their large oil stocks.[77]

As a consequence of the fuel shortages of the war, in fact a West-Danish centralized system was established. For besides the construction of a power grid, electricity production was increasingly concentrated in the large power stations of the Southern Jutland utility and the Århus municipal utility. In the beginning of the war, the Southern Jutland utility signed contracts of electricity sale to the partnership South-Eastern Jutland Interconnection (1940), the partnership of South-Western Jutland (1941) and the Funen interconnection (1942).[78] The Århus utility entered the co-operation originally to acquire back-up capacity for the Mid-Jutland centralized system from the Southern Jutland utility. However, as the surplus capacity of the latter was quickly occupied, it ended up supplying large quantities of electricity to both the South-Eastern Jutland Interconnection and the Southern Jutland utility.[79] Moreover, during the last year of the war the co-operation committee agreed only to run the largest power stations in Århus and Åbenrå normally, while the power stations in Esbjerg and Odense were kept in part-time operation, and the other power stations were shut down completely.[80]

From the perspective of war-time electricity supply, the centralized system proved very successful, and was praised by most participants. For together with additional restrictions on electricity consumption, it managed to largely keep up electricity supply during the crisis. From the perspective of the diffusion of centralized supply, however, the system was only a temporary success, as the concentration of production was maintained only until diesel oil again was available. On one hand, this was possible because the smaller utilities had insisted upon their right of decentral production and expansion. For instance, the contract between the partnership South-Eastern Jutland Interconnection and the Southern Jutland utility of 1940 specified that the parties *could choose to* exploit their engines as economical as possible, but also that the former maintained the *right* of decentral expansion, whenever it wished to do so.[81] And on the other hand, although the West-Danish centralized system could maintain electricity supply despite fuel shortages, it could not demonstrate the economic superiority of concentration of production. On the contrary, as the available production capacity was small relative to the demand, the large scale production machinery run at a constant overload, and thus with much reduced turbine and boiler efficiencies.[82] By the end of the war, their machinery was worn out, and hardly suited for economic electricity production.

As a result, the municipalities owning decentral systems saw the concentration of production only as a temporary arrangement. After the war, they massively resumed decentral electricity production, even though a power grid now was available. As table 1.1 illustrated, nearly all decentral town-based production systems were still productive by 1950. And although they might use this grid to purchase additional electricity, the table also shows that their accumulated production increased between 1940 and 1950. In this sense, the model of 'decentral co-operation', explicitly developed by the partners in the South-Eastern Jutland Interconnection in the 1930s, had been elevated to a general supply model for the municipal utilities in Western Denmark. The same was true in Eastern Denmark, where the remaining isolated town systems also had been connected to the grid during the war, but also resumed decentral production afterwards.

In sum, municipalities generally found the consolidation of decentral town systems feasible until the 1950s, and possibly also later if special circumstances applied. The establishment of the West Danish power grid and a large number of connections to smaller systems, however, had also improved the economic feasibility of centralized supply greatly, since these heavy investments were excluded from the cost picture. While almost a hundred decentral town systems were still running by 1950, in the following decades they were rapidly closed down to the advantage of electricity purchase from centralized systems (see chapter nine): By 1970, only eight town systems remained (excluding CHP plants run by heat utilities, which are excluded in the electricity supply statistics). The seven of them were run by a single municipal utility, while the large town-based system on the island of Bornholm was commonly owned by the municipalities of six market-towns as well as consumer associations. Notably, six of these systems produced only a marginal share of the electricity supply of their supply area: Besides the CHP plant in Copenhagen, this includes a number of very small hydropower plants, which were maintained because of their low running costs, but which had a negligible electricity production. As a result, the only town-based systems that fully maintained their importance were those on Bornholm and in Randers, which together accounted for almost all electricity output in decentral town systems. But here special circumstances applied: The latter system remained economically feasible due to its well-managed CHP plant, while the former system was situated on a rather isolated island between Sweden and Poland in the Baltic Sea, which made it difficult to integrate in a centralized system. In fact, the Bornholm system was only connected to the East-Danish centralized system in 1980 through a rather complicated connection, which involved the submarine cables under the Sound, the Swedish power grid and a new submarine cable from Southern Sweden down to Bornholm. From then the Bornholm supply company purchased its electricity, although it maintained its district system for supply in case of a break-down of the submarine cable.[83]

8
Consumer associations and the consolidation of rural systems

Even more surprising than the consolidation of municipal town systems, perhaps, is the consolidation of a large number of decentral rural systems, overwhelmingly run by the actor group of consumer associations. For in addition to the competition from centralized systems, these also competed with many town-based district systems, which expanded into the hinterland. But although their number gradually declined, by 1950 there remained more than two hundred and twenty local village systems, which were often consolidated despite the presence of transmission grids in their immediate vicinity. Moreover, their accumulated output had almost four-folded since the early 1920s (table 8.1). There was also a small number (about ten) of rural district systems), but local village systems dominated the consolidation of rural systems both in numbers and in output. Even more so if the local systems in small 'rural' towns are included; such systems had often been founded by consumer associations in villages, which had subsequently grown into small towns, as they obtained more than a thousand inhabitants. Still, the utilities running such small town systems counted themselves as part of rural Denmark, and adhered to the same rural discourse of decentral supply and rural interest organizations as village utilities, while also the decision process was similar - the general assembly of consumer-owners had the decisive say. By 1950, there were still more than thirty of such 'rural' town systems. In sum, the majority of decentral rural systems was maintained until the 1950s; only in the 1950s and 1960s also these systems virtually disappeared.

Table 8.1: Decentral rural electricity supply systems in number and output 1923-1970.[1]

		1923/24	1931/32	1939/40	1950/51	1960/61	1970/71
Local systems	n	358	335	316	222	83	7
	GWh	14	20	30	53	33	0
District systems	n	13	11	13	11	9	6
	GWh	11	7	10	30	19	19
Total	**n**	**371**	**346**	**329**	**233**	**92**	**13**
	GWh	**25**	**27**	**40**	**83**	**52**	**19**

Like in the previous chapter, the successful consolidation of decentral rural systems is studied through the general debates, the policy of interest organisations to maintain autonomy of decision for their members, and concrete decisions in individual rural utilities. Due to the large number of rural systems, only the decision process of a single utility is studied in depth, while many other cases are consulted to investigate in how far it is representative. Finally, also with regard to decentral rural systems there were special circumstances which might make them economically feasible even in the 1960s; this was particularly so for systems exploiting hydropower plants and systems situated on some of Denmark's many small islands.

The status of decentral rural systems in technical circles

Decentral rural production in the discourse of centralization

From the point of view of propagators of rational large scale supply, the consolidation of small rural systems was even more irrational than that of medium and small sized town systems. They frequently referred to the economical and technical inferiority to argue for the abolition of decentral forms of electricity supply; in his plea for centralized supply in 1917, NESA-director Angelo had plainly urged that no more small rural systems were established for the sake of the national economy. This particularly concerned local systems, as these were difficult to integrate in a large scale supply scheme, which would operate with alternating current. With regard to existing decentral rural power plants, Angelo had suggested that they be shut down and rebuilt as conversion or transformer stations, thus becoming distribution stations in a large scale supply system.[2] Moreover, in the following discussion such small rural systems had been pictured as economically hazardous and technically unreliable from an engineering point of view. This was often due to the lack of proper engineering assessment and design; to the discontent of electrotechnical engineers, village systems were often designed and constructed by local or regional 'installation firms', convincing rural actors of the benefits of their systems only to score a quick profit from selling expensive equipment. As consulting engineer and co-founder of the large South-Eastern Zealand district utility SEAS, Frederik Krebs, put it, 'I must protest to calling these people real consultants - the term acquisition agents would be more appropriate.'[3]

To explain the consolidation of such small rural systems despite the technical-economic improvements and geographical expansion of large scale supply systems, propagators of centralized supply often referred to 'local patriotism' of local communities, that is, a socially or politically motivated strive for independence. Thus, like in case of town systems, a part of the discourse of centralized supply was to render economically irrational the establishment and consolidation of small rural systems. For instance, in his comment on the 'cavalcade of madness' of decentral systems at the eve of the Second World War, Holger Hasselbalch Larsen's described the consolidation of small rural systems as an expression of an urge for independence, which caused particularly the Jutlanders to refute the work of Electricity Council in Copenhagen - an urge 'both to laugh and to cry about' for the rational engineering community.[4]

A piece of counter propaganda

From the point of view of actors engaged in decentral electricity supply, the matter looked obviously different. Spokesmen for decentral supply systems recognized this asserted claim of the irrationality of decentral production systems as a piece of unnuanced propaganda, aimed to support the introduction of centralized electricity supply. In response, some parties with a stake in decentral local systems launched a counter propaganda for decentral supply. An example is the brochure called 'a defence for local systems' issued by the firm Møller & Co in Odense in 1927. Having a concrete business interest in the consolidation of local systems as a supplier of accumulator batteries[5], the firm lined up several arguments for small rural utilities to maintain a decentral production.[6] For instance, it refuted the claims of the inferior economical and technical performance of such systems. With regard to economy, it used the electricity supply statistics to argue that utilities exploiting decentral production in local systems - particularly in larger villages or small towns - only rarely found an economic profit by purchasing their electricity from outside, as they often operated with lower prices than the large rural district utilities. And with regard to technological performance, it used newspaper articles on recent break downs in large scale systems - particularly in high voltage transmission systems - to illustrate the superior technical reliability of local systems. In addition, it mobilized the physiological danger of high voltage, alternating current, a well known argument against large scale supply since the international 'battle of systems' in the 1890s. And finally, it also stressed the advantage for small villages to have a local plant manager; this not only meant local employment for the village community, but also that consumers had cheap and quick access to a person capable to repair installations and appliances. From these arguments, the firm concluded that for the economical and reliably run local system, large scale supply - here identified as 'alternating current supply' - did not have 'any interest whatsoever'.

The polemic tone of the brochure provoked an equally polemic response from propagators of centralized supply, which suspected the firm for seeking to induce an unfounded rural bias against large scale supply, and rejected all its arguments as dubious, untrue or irrelevant.[7] The security of supply argument was rejected with reference to technological improvements on the field, which had made 'break downs a rarity'. Likewise, the danger of high voltage, alternating current systems was hardly an issue, if the installations were carried out carefully and skilled, and used reliable materials. The argument of the advantage of a local plant manager was completely ridiculed: Rather than a source of quick and cheap repairs, the local plant manager often proved a cause of the poor technical state of many rural installations. This was the result from his lack of skill, as well as his busy job both as plant manager and electrician. But most important, the key argument of the economic feasibility of decentral rural systems was criticised. Besides accusing the brochure for selective use of the electricity supply statistics, rural utilities were accused of a low maintenance efforts and too low repayment rates. This might result in low electricity prices, but could also cause that the machinery was worn out before it had been repaid. On the other hand, the response recognized an economic advantage of rural local systems to all systems involving high voltage transmission; most transmission lines were build during and after the First World War at comparatively high costs, while the bulk of local systems had been built before the war at low, pre-war prices.[8]

Decentral rural systems and their consulting engineers

More surprising, perhaps, is that arguments for the economic and technical feasibility of decentral local system were also made within the engineering community. Here decentral supply systems were occasionally defended by consulting engineers, which on one hand might also have a stake in decentral supply, but on the other hand had access to much more detailed and accurate information on the technical and economic performance of small rural systems. In addition, they shared the education and engineering ideals of the propagators of centralized supply; this was for instance expressed in their disrespect for the work of installation firms engaged in many small rural systems, which lacked engineering qualifications, and thus were unable to make a proper feasibility study.

An early example is the argument made by consulting engineer Ernst Johansen in 1913. Johansen himself was one of the first electrotechnical engineers educated in Denmark (1907), who after some years of work in the Electricity Commission started his own consultancy firm, and designed a number of small rural supply systems. Provoked by the unambiguity of a plea for district supply by his former teacher professor Rung, he engaged in a discussion with Rung on the economic feasibility of small local systems.[9] According to Johansen, many rural local systems - in particular those, which had been designed by engineers rather than installation firms - could compete economically with large district systems, as concrete examples could illustrate. A small village system in Vejlby (four hundred inhabitants) on Lolland, for instance, operated with running costs comparing to those of the large Northern Zealand district utility NESA, which represented state-of-the-art large scale supply. As the bulk of district systems had significantly higher production costs than the

NESA, local systems might in fact very well be economically superior. Johansen explained the low running costs of rural local systems by the advantage that their production machinery only run part of the day, while batteries took over supply during periods of low consumption. District systems, by contrast, might achieve economies of scale, but using alternating current technology they could not use batteries, and thus had to run their production machinery twenty-four hours a day. This gavemuch higher fuel costs and operator wages. Besides, such machinery would wear out sooner. Johansen's conclusion was that district supply was only appropriate, if the scale of supply made transport the crucial economic factor: This happened if the supply system geographically expanded more than three or four kilometres from the power station, or if the load exceeded that of about five thousand lamps and four hundred horsepowers.

Although Johansen's argument was severely criticised by Rung, few years later the economic problems of district systems were generally recognized and received ample attention from electrotechnical engineers - including Rung.[10] Among the much discussed economic problems discussed in the late 1910s was the necessary overproduction of electricity by district systems, resulting partly from the unfavourable exploitation of machinery (a low load factor), and partly from significant losses in the transmission system. It was not uncommon that district systems only sold fifty to sixty percent of their production. Even the largest district systems, such as those of SEAS in South-Eastern Zealand and NVE in North-Western Zealand, sold less than seventy percent of their electricity produced in 1916-17.[11]

Other consulting engineers repeated Johansen's argument in the following decades. In the late 1920s, for instance, consulting engineer Karl V. Haar protested to the description of rural local systems as 'economically and technically unfeasible.' Also a first generation Danish electrotechnical engineer (1910), Haar was the co-owner of the consulting engineering firm Haar & Hunderup Jensen, which designed electricity supply systems and waterworks.[12] Notably, Haar agreed to the national-economic rationality of large scale supply, and he also complained that small rural systems often expanded decentrally without a thorough feasibility study. Still, he acknowledged that the decentral expansion of production capacity often was economically rational from the point of view of the small rural utility. In a typically engineering way of arguing, he provided a hypothetical example 'which reflected conditions as they often are' (table 8.2). Thus he compared the expansion of a village system with a new diesel generator with the purchase of additional electricity from a transmission grid through a converter. A third option, to take all electricity from the grid through a transformer, could be dismissed at once as economically unrealistic; for this would imply that consumer-owned utilities had to change their distribution networks, electricity meters, consumer installations and part of the appliances (such as electric motors) for alternating current operation, and in practice consumer associations would eschew the high costs of such a measure. The result of the comparison was to the advantage of the decentral expansion scheme, which despite considerably higher investment costs had lower annual costs. This followed particularly from the low fuel expenses relative to the high costs of electricity purchase, even though - according to Haar - the purchase price (made up of a kWh price and an annual fee to cover interest & repayment of a transmission line) was set low compared to the actual pricing practice of district supply companies.

Table 8.2: Haar's calculation of the annual costs following two expansion options for a hypothetical local village system with 20 MWh annually (Haar 1927).

Expansion with a 70 hp. diesel power unit		**Expansion with a 45 kW convertor for electricity purchase**	
Investment costs:			
Diesel power unit:	28.000 DKK	Conversion equipment:	12.000 DKK
Annual costs:			
Interest & Repayment (10%):	2.800 DKK	Interest & Repayment (10%):	1.200 DKK
Maintenance:	800 DKK	Maintenance:	350 DKK
Fuel & lubricating oil:		Electricity purchase:	
20.000 kWh à 5 øre:	1.000 DKK	25.000 kWh (20% loses*)	
		à 15 øre:	3.750 DKK
		Transmission fee:	500 DKK
Total:	**4.600 DKK**	**Total:**	**5.800 DKK**
pr. effective kWh:	23 øre	pr. effective kWh:	29 øre

* Electricity was purchased at the high voltage side of a transformer. Therefore, transformer and conversion losses had to be included.

In addition to this economical feasibility of small scale supply, Haar argued that such systems also might have a technical advantage on the field of reliability; still in the late 1920s, the reliability of decentral local systems with battery back-up was superior to that of systems involving high voltage electricity transmission, as particularly problems on transmission lines often caused power cuts. Also this problem had been generally recognized in engineering circles in the late 1910s. For instance, NESA-director Angelo had recognized that the lacking reliability of high voltage transmission gave decentral actors - utilities as well as autoproducers - good reason to maintain their own power stations.[13] In the late 1910s, breakdowns in transmission systems often resulted from mechanical problems, which could be solved by better construction methods. In some places, storm, snow and ice almost 'guaranteed' power cuts, as they caused transmission lines to collide and short circuit. Another problem was that birds, particular starlings, would settle upon transmission lines 'by thousands'. Also these might cause a short circuit, which probably has caused 'thousands' of casualties among birds, besides frequent system break downs. Other break downs followed electrical phenomena, such as system overflow resulting from short circuit or resonance. In these cases, the currents in the transmission system might suddenly increase to levels far higher than the equipment could take, and for instance burn out transformer or generator coils, or ignite the oil in circuit breakers. In sum, there was plenty of room for technological improvement.[14] By the late 1920s vast progress had been made, but incidental breakdowns continued to characterize high voltage transmission systems.

A final example, a talk of consulting engineer Aage Brix-Pedersen at the association of rural utilities in Jutland in 1949, illustrates that small scale systems might still be regarded economically and technically feasible after the Second World War despite continuous improvements in large scale system economy and technology. Also Brix-Pedersen was educated as an electrotechnical engineer (1937), and from 1942 co-owner of the consulting firm Brix-Pedersen & Kamp Jørgensen. In addition, he was engaged in executive boards of engineering fora such as the regional sections of the Electrotechnical Society and the Danish Association of Engineers.[15] Still, Brix-Pedersen recognized that as long as rural local systems were not expanded beyond their economical supply area of a few kilometres, they might very well compete economically with large scale systems. With the exception of very small systems, even the decentral expansion of production capacity might be economically feasible. And with regard to technical performance, he stressed that reliability remained a major advantage of local systems, still being superior to systems involving high voltage transmission on this field. In sum, it would be misleading to characterize the engineering community as such as condemning the feasibility of decentral rural supply systems; rather, electrotechnical engineers had different views on the subject, often following the type of systems they worked with.

The rural discourse of decentral production

The interest organisations of rural utilities

Consulting engineers, however, were merely one input in the debate on the consolidation of small rural electricity supply systems. Most important for the actual decision processes, no doubt, were the ideas and sentiments that circulated within the actor group that owned and run the decentral rural systems. Fora for such circulation appeared particularly in the second half of the 1930s. Already in the 1910s the plant managers of rural systems had founded regional associations on Funen (1913) and Lolland/Falster (1915), and in the 1930s similar associations were founded for Jutland (1932) and Zealand (1936). Yet the focus of such organizations remained narrow; particularly before the 1930s, they primarily provided a context for plant managers to meet socially and exchange experiences, and serving interests primarily meant negotiating with utilities on wages and labour conditions of plant managers, as well as arranging pensions.[16] Only later, in the turbulence of the 1935 Electricity Supply Act, the plant manager associations became concerned with the consolidation of decentral systems: The different regional associations started a co-operation, and their representatives met with Parliamentary committees to explain their point of view. At the same time, the plant manager association on Jutland started the monthly newsletter *Månedsmeddelelser*, which soon became a common organ for all plant manager associations, and expressed a discourse for decentral production.[17]

On the other hand, actual interest organisations for rural utilities were also established; contrary to the plant manager associations, these represented consumers and owners as well as plant managers, and were primarily concerned with the consolidation of rural systems.[18] During the late 1910s and early 1920s, associations of rural utilities were established on Funen [*De samvirkende land-elektricitetsværker i Fyns stift*, 1917] and Lolland [*De samvirkende elektricitetsværker i Maribo amt*, 1922]. In Jutland and on Zealand, permanent interest organisations [*Foreningen af Jydske elektricitetsværker* and *Foreningen af Sjællandske jævnstrøms-elektricitets-værker*] were first established as a response to the 1935 Electricity Supply Act, which had taken many executive boards by surprise, and was experienced as a threat to their autonomy. The largest and most influential of these was the Jutland association, because the large majority of decentral rural utilities was situated here.[19] Its purpose was explicitly to defend the interests of rural utilities against interference by national authorities, and to influence the Electricity Council and Parliament. In addition, it provided assistance to its members; for instance, it handled the expansion applications to the Electricity Council on behalf of its members.

Also as a result of the 1935 Act, the regional associations of rural utilities started a national cooperation, which soon developed into the Danish association of rural utilities [*De danske jævnstrømsværker*], which also became a member of the Danish association of utilities DEF.[20] And like the plant manager associations, also the utility associations shared a newsletter called *Elektriciteten,* started in 1938 precisely to improve the communication among the different rural utilities and thus improve there coherence as an actor group, and thereby 'prepare the work for maintaining the autonomy of small utilities.' To this purpose, it was to be freely distributed to all rural utilities in Denmark.[21]

Rural interest organisations and the emerging discourse of decentral supply

It was also in response to the 1935 Electricity Supply Act and the establishment of the Electricity Council, in which small rural utilities were not represented, that spokesmen of rural utilities first mobilized a rhetoric repertoire defending the consolidation of decentral systems. A first element of such a discourse of consolidation, particularly in the first years after the 1935 Act, was a strong distrust of the new Electricity Council. This distrust was perhaps most forcefully expressed by bank manager C. E. Jensen of the rural utility in Mørke, Jutland. Jensen was also the first secretary of the Jutland association of rural utilities, and chaired its negotiations with the Electricity Council in applications for decentral expansion on behalf of its members. Jensen gladly drew upon the social cleavage between the capital and provincial Denmark, when he completely rejected the supposed neutrality and competence of the Electricity Council. For instance, he suggested a bias resulting from the fact that its engineers were all educated at the Polytechnical School in Copenhagen with electrotechnology as their specialty, and had very little knowledge of the specific situation of rural utilities. Jensen found this bias clearly revealed in the way, in which the Council treated the applications for decentral expansion: While the Council often failed to interpret the relevant variables correctly and - according to Jensen - structurally recommended the economic benefits of electricity purchase, Jensen's own 'dry numbers' showed that decentral production in local systems gave the 'best and cheapest electricity'. Correspondingly, rural utilities usually rejected the recommendations of the Council, thus proving that they 'do not want to be governed by an office in Copenhagen, but desire full autonomy of decision.'[22] Jensen build his arguments around such suspicion of a Copenhagen bias at least until the 1950s.[23]

A second element in the discourse of consolidation of local village systems is the mobilization of concrete economical and technical advantages of such systems. These were for instance analysed in a contribution by Harald Villemoes, the plant manager of the village utility of Ulfborg (and later Hurup), and also chairman of the Jutland association of plant managers and editor its newsletter. Villemoes agreed with Jensen that the calculations of the Electricity Council might 'have nothing to do with reality'[24], and was also annoyed by the unnuanced propaganda of advocates of centralized supply. The national-economic argument against local village systems was particularly absurd: As such systems only represented few percent of the national electricity production, they could hardly threaten the national economy, and their closing down would not give national economic gains of any significance. Yet, he insisted on a less polemic tone than Jensen in order not to develop the opposite bias. Thus he would not exclude the possibility that large scale supply would dominate the future, and agreed that several village systems operated with very high electricity costs and prices, and would be better off with electricity purchase.[25]

Still, for the time being there were also many well-administrated and well-operated village systems, which could produce electricity more cheaply and more reliably than larger systems. Their economic feasibility was on one hand due to the high electricity prices of larger utilities. For only very few large power stations had in fact the low production costs that were often claimed. In addition, electricity transmission on high voltage networks increased the total costs of centralized supply considerably. An example was the prestigious power plant of the Southern Jutland utility in Åbenrå, the largest power plant in Western Denmark: While this plant indeed produced electricity at very low costs (1 øre/kWh), by the time it reached the distribution companies at the West coast the costs had nearly four-folded (to 3,5 øre/kWh). And on the other hand, the production costs of local village systems could be very low, and made most such systems competitive. For although village systems could not exploit scale advantages, they were often administrated particularly economically, while technological progress also benefitted small systems: Of particular importance was the high fuel economy of modern diesel engines even in very small units. In addition, direct current generators had the advantage of easy adaptation to changing loads (simply by changing the speed of the engine) and thus easily achieved an optimal load of the production machinery. The operation of transformers for receiving electricity from outside, by contrast, could not be similarly adapted, and would typically have idler losses of some 35-40% when demand was low.

In addition to this explanation of the economic feasibility of local village systems, Villemoes included several other arguments for maintaining decentral production systems. One was the superior reliability of local village systems, which had been demonstrated again during the heavy snow fall in the last winter, when many consumers of large transmission companies had experienced power cuts lasting for several days. For large-scale supply to be technically reliable, the receiving village station should be supplied at least by two independent transmission lines; yet, this again increased the investment and maintenance costs of large scale supply.

Finally, there were some local-economic disadvantages of electricity purchase. The shut down of the local power station would imply the loss of capital that perhaps had not yet been written off. And another spokesman of decentral supply, Vilhelm Mondrup - the chairman of both the Jutland and national association of rural utilities - added that a reduction of local employment would outweigh possible economic gains of electricity purchase.[26] He found it reasonable, that even if there was a small saving in electricity costs in the purchase scheme, local concerns such as reliability and local employment tipped the scale to the advantage of decentral production.[27]

A third and final element in the discourse of consolidation of local village systems to be mentioned here is the reference to the preservation of local autonomy. For propagators of centralized supply, this term referred to social stubbornness and technical-economical irrationality of rural utilities. Yet for the rural utilities, local autonomy was a concrete political goal, which combined the fear that national authorities would superimpose large scale supply through legislation with the claims of the economic and technical feasibility of decentral systems: In this context, local autonomy meant the right of individual utilities to choose the technically and economically most rational supply option. As Vilhelm Mondrup put it, the primary task of the interest organisations for rural utilities was to ensure the autonomy of decision of the individual rural utilities, so that they could chose the best supply system with regard to economy and technology, regardless if this was decentral production or purchase from a larger utility. Contrary to propagators of centralized supply, he found the executive boards of rural utilities fully competent to make such decisions; these boards were made up by 'businessmen, farmers and others, who surely can calculate which is the cheapest option.'[28]

Yet, Mondrup and the other chairmen of the regional associations of rural utilities knew that strong political sentiments occasionally might govern the decisions of their members. In this context, they repeatedly advised members not to maintain decentral production out of stubbornness or sentiments alone, as this would damage the reputation of rural systems, and perhaps increase the odds of government intervention.[29] Although such advise might lead to conflicts within the organisations, there was no substantial disagreement on this issue; even the fiercest critics of centralized supply and of the politics of co-operation between rural associations and the Electricity Council, such as C. E. Jensen, emphasised that the task of the executive committee of a rural utility was to ascertain its consumers electricity in the 'best and cheapest way'. The day that large power stations supplied electricity sufficiently cheap and without power cuts, the executive boards of rural utilities would gladly accept to purchase their electricity.[30]

The emergence of a rural discourse of consolidation of local village systems, then, does not imply the absence of conflict among spokesmen of rural systems. For instance, C. E. Jensen was repeatedly in conflict with the executive board of the Jutland association of rural utilities, which he regularly accused of incompetence. The board, in turn, relieved Jensen from his duties in the negotiation committee of the association in the late 1930s as a direct result of his 'rude', 'uncontrolled' and 'insulting' tone against the Electricity Council. And several decades later, when the boards of the regional associations provided guidance for their members on the options of electricity purchase, they were accused of 'shameless eagerness to convert to alternating current supply'.[31] In response, they might again accuse members of irrational opposition to alternating current.[32] Such internal struggles concerned the political strategy of the associations, however, while there was a broad consensus upon the principal criteria of judgement of the different supply options: These options should be judged on economy and reliability.

During the crisis of the Second World War, the normal concerns yielded for concern for fuel supply (see below). After the war, however, the pre-war elements of the discourse of consolidation of rural systems were again forcefully presented. For instance, Mondrup rejected the 1946 report of the government committee 'Electricity Committee of 1941', which again recommended centralized supply. He found the report unqualified, as the committee only represented directors or plant managers of the largest utilities in Denmark: Had smaller municipal utilities and rural utilities been represented, the conclusions might not have been the same. And in defending the rationality of decentral production, he again pointed at its technical and economic feasibility: As village systems would have to be connected to the transmission networks as the 'furthest link on the chain', they would be most vulnerable for transmission failures in a centralized supply system. Moreover, the conditions for electricity purchase were unacceptable, characterized by comparatively high prices and brief contracts (and thus a risk of future price increases).Yet decentral supply systems usually satisfied their consumers; thus, the small utilities 'knew what they had, but not what they would get'.[33] Also the chairman of the Funen association of rural utilities maintained that large scale supply was too expensive, not in the least as large power plants were obliged to use indigenous fuel (lignite) to save on imports according to post war valuta policy. Likewise, he stressed the superior reliability of local systems.[34] Finally, also the chairman of the association of rural utilities on Lolland and Falster agreed that the high prices offered by large utilities obstructed centralization. He accused the pricing policy of large utilities, which deterred small utilities and stimulated the purchase of decentral production machinery.[35] At the level of interest organisations, then, the arguments for decentral production remained valid.

Autonomy and the political strategy of rural interest organisations

Contrary to the association of Danish utilities and the association of municipal utilities, associations of rural utilities did not have any formal ties to the legal authorities on the electricity supply field. Neither were they heard in the legislative process leading to the 1935 Electricity Supply Act. The only protest from their side were few rather hasty and improvised appeals of representatives of the plant manager associations, which had heard of the bill though their reading of the journal *Elektroteknikeren,* to Parliamentary committees studying the matter.[36] According MP Kay Emun Rager, however, these appeals had not gone unnoticed, and the interests of rural utilities had been defended in Parliament.[37]

Under all circumstances, although there had been some initial confusion on the contents of the new Act, the rural utilities soon realized that they had kept their decentral autonomy of decision. As it was occasionally put, this autonomy was only taken away for three months - the maximal period of time for the Electricity Council to treat an application for the expansion of decentral production capacity. Yet even this small delay annoyed utilities, particularly if an expansion was urgent, for instance to meet the coming electricity demand of the winter time. Moreover, the interest organisation of rural utilities knew that the Electricity Supply Act was due for revision in 1940, which might result in an increased competence of the Electricity Council if the current arrangement would not result in a rationalization of the supply structure.

The question, then, was how to avoid a further reduction of local autonomy. As mentioned above, it was this issue of strategy that gave rise to serious conflict within the interest organisations of rural utilities. In the most important organisation, the Jutland association of rural utilities, C. E. Jensen confronted the rest of the board: In his view, the association should seek conflict with the Electricity Council. He proposed to the assembly to accept a resolution, stating that the association was dissatisfied with the work of the Council, and urged the association board to work for a change of the 1935 Act to give back full autonomy to the utilities - that is, abolish the three month 'delay period'. The resolution was not voted upon, however, and chairman Mondrup rejected this strategy; according to him, the association should seek the recognition of the Electricity Council, and gain influence as a credible partner in negotiations.[38] Mondrup's view won, and Mondrup concretely took over Jensens role of negotiator towards the Council together with two plant managers. The strategy to work with, instead of against, the Electricity Council bore fruit: Mondrup was accepted as a negotiation partner, and soon gained an important say in the treatment of the Council of expansion cases.[39] And when the Act was evaluated in 1940, the competence of the Electricity Council was not increased, despite the fact that the decentral supply structure in Denmark had not changed at all. Instead, Mondrup was invited as a permanent member of the Council. In this position, he expected to be able to exert influence: He would represent specific economic and technical knowledge of small rural systems, and possibly be able to avoid most of the much hated 'declarations' of the Council, which widely publicised the irrationality of decentral expansions of concrete utilities.

Soon, however, the autonomy of rural systems was challenged by the fuel shortages of the Second World War and the appointment of the 'Electricity Commission of 1940', which had the competence to arrange electricity supply and distribution in a fuel-economic way. In a first decree, the commission told most diesel powered systems to try to connect to the nearest transmission network in order to purchase electricity from a steam power station. The interest organisations of rural utilities, however, pointed at another option: Small rural power stations could be adapted to be driven by renewable or indigenous energy sources. Already in 1939, when diesel prices increased, the associations had invited advise on this matter from its technical consultants as well as leading machine factories in the country.[40] For instance, it published articles from leading diesel engine manufacturers such as Burmeister & Wain in Copenhagen, A/S Frichs in Århus and Bukh in Kalundborg, on how to adapt diesel engines to operation with different fuels such as petrol, train oil, or oil from tar if these were available. Much more important, however, was that diesel engines could easily be rebuilt as suction gas engines, which facilitated the use of gasified solid fuels as cokes, coal, peat or wood. During the final years of the previous war, the Burmeister & Wain company had rebuilt some hundred diesel engines to suction gas engines, primarily fuelled by peat; the technology was thus readily available.[41] On request of a number of members, another article was invited to present the state of art of wind-electric power production.[42] The local system in Askov, the exemplary system of wind-electricity in the first decade of the century, was again taken as an example: By now the system had an annual production of some forty megawatthours with a new model of windmotor, produced by the factory Lykkegaard, which supplied windmills for many local village systems. In view of the rising diesel oil prices, such windmills would be economically feasible. Moreover, the large firm F.L. Smidth & Co would soon bring its improved propeller mills on the market.[43] Finally, another alternative for rural utilities was to co-operate with local industries with steam power units.

The arguments of spokesmen of rural utilities for the consolidation of decentral production were adapted accordingly, from focusing on the economy and reliability of the single utility to focusing on ir fuel-efficiency from a national perspective. Whereas the ‘Electricity Commission of 1940’ claimed that the national fuel efficiency could be raised through the concentration of production, a consultant of the interest organisations of rural utilities, plant manager Harald Jensen of the Brørup utility, came to an opposite result. According to Jensen, centralized production would not necessarily save national fuel reserves, partly because of the losses in transmission systems (lines, transformers and convertors), and partly because the boilers of large power plants were not designed for burning indigenous fuel, which should be used during the war. Therefore, they would not be more efficient than small suction gas engines. This was concretely illustrated in a series of tests conducted at the Bukh diesel engine factory: Diesel engines adapted to suction gas in local systems had a higher efficiency than the largest power stations in Jutland according to the 1937 electricity supply statistics, if power losses of twenty-five percent in the transmission system were included.[44]

Although the Electricity Commission of 1940 might not use actual force, it did have the authority not to approve such decentral constructions of suction gas engines. In response to the decree, representatives for the rural utilities therefore sought negotiations, arguing before the Electricity Commission that for small rural utilities the expenses of connection would be disproportionally large, while on the other hand they had particularly easy access to local peat bogs, which could supply small suction gas engines.[45] Mondrup also mobilized the investigation of the efficiency of suction gas engines, although the Electricity Commission criticised its outcome.[46] Under all circumstances, in the end the Commission agreed on a large degree of freedom for the rural utilities: It would approve all 'expansions' carried out prior to its constitution, all expansions involving renewables such as wind or hydro power, all expansions of utilities, which received unfavourable offers for supply through a transmission network, and the co-operation of a number of utilities with local industries. Out of some three hundred and sixty small rural utilities, this left merely thirty utilities, which had no choice but to connect to high voltage lines. In addition, some eighty utilities voluntarily connected to a transmission system for temporary electricity purchase. The large majority (about two-thirds) of the rural utilities, then, was allowed to adapt its decentral production capacity; of these, most introduced wind power or rebuilt their engines for suction gas, while the remaining ones used hydropower, refuse or oil reserves.[47] Contrary to the municipal utilities, which mostly participated in ambitious interconnection schemes, most rural local systems thus continued operation in complete isolation from expanding high voltage networks.

Case: Decentral expansion of the local village system of Aså 1936-1948-1955

How, then, did individual rural utilities motivate the consolidation of their decentral production systems, despite the continuous economical and technical improvement and expansion of large scale supply systems? A village system, which lends itself to detailed investigation of the motives for consolidation and even decentral expansion of production capacity, is the village utility of Aså in Northern Jutland. Situated at the Eastern Jutland coast just above the Limfjorden, Aså was a medium-sized village (700 inhabitants in 1915; 1366 in 1993) with its own railway station and a small harbour, and had its consumer owned electric utility since 1908. Until its supply system was finally shut down in the early 1960s, the decentral production capacity of its local system was expanded several times in the 1930s, 1940s and 1950s. This was so despite the fact that the high voltage transmission grid of the municipal utility of Nørresundby, in the supply area of which Aså was situated, had reached the surroundings of the village by the late 1920s (figures 8.1 and 8.2). As the Nørresundby municipal utility in turn received its electricity from the largest power stations in the region - first from that of the co-operative cement factory, and from the early 1950s from that of the municipal utility of Ålborg, the Aså utility rejected purchase from a large scale system

What, then, caused the Aså utility to decentrally expand its small local system instead of purchasing electricity from outside? In its first application for an expansion to the Electricity Council in 1936, the utility desired to expand its small (forty kilowatts) power station with a second diesel power unit (twenty-three kilowatts) to ensure back-up capacity.[48] Through the Jutland association of rural utilities, which it authorized to handle the application and negotiations with the Electricity Council, it notified the Council that it had not considered supply from Nørresundby, as it eschewed to repeat similar negotiations that had collapsed half a decade earlier. The Electricity Council then made an economical assessment of two options; besides the decentral expansion scheme desired by the Aså utility, it investigated the option of closing down the decentral power station and changing the system for alternating current supply, delivered by the Nørresundby utility. A third option, to combine continued decentral production with purchase of additional electricity through a convertor, was not investigated, as the investment costs as well as running costs (still including wages and maintenance) certainly were higher than in case of full decentral production. To assess the economy of the purchase scheme, the Council collected an offer for supply from the Nørresundby utility: According to the terms of this utility, the Aså utility should finance the 2.4 kilometres of transmission line from its transmission network to the village, as well as the transformer station, which should replace the village power station. In addition, it demanded a minimum annual purchase and specified its prices.

From this information and data supplied by the utility, the Council could make its assessment (table 8.3). The investment costs of the decentral expansion were much lower than those of the purchase scheme; a new diesel power unit could be installed for twelve thousand krones, while a change to alternating current supply would cost almost four times as much. This was particularly due to the change of direct current to alternating current distribution, which demanded a change of distribution network as well as electricity meters, installations and some appliances (for instance motors and radios) at the single consumer. While municipally or privately owned utilities might not include consumer expenses as a utility expense, and simply tell the consumers to change their installations and appliances, in the case of rural co-operative societies the consumers had the power of decision, and thus included consumer expenses in the picture. With regard to annual expenses calculated three

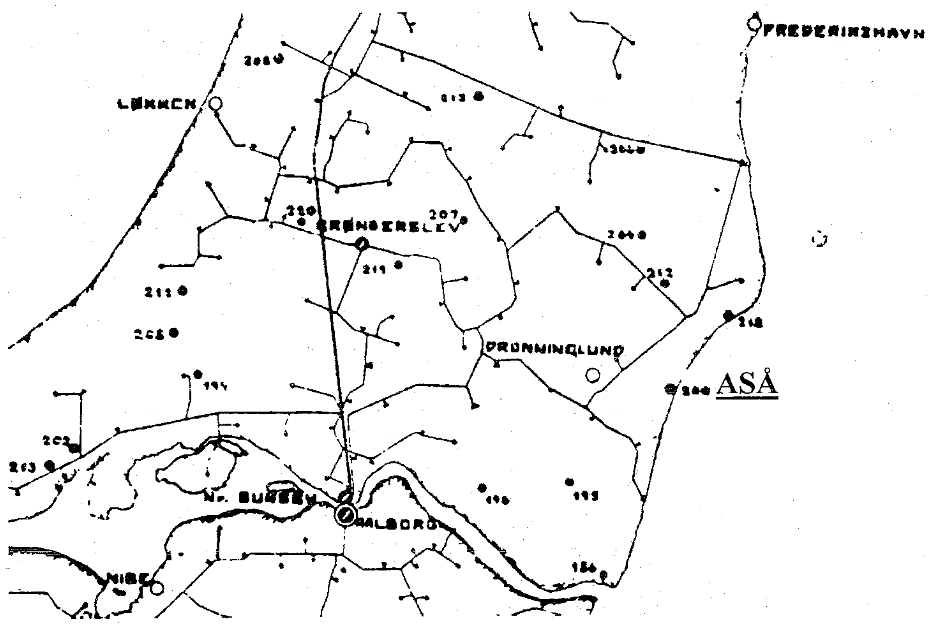


Figure 8.1: Transmission lines surrounding the village of Aså by 1929. Source: Elektricitetsrådet 1957

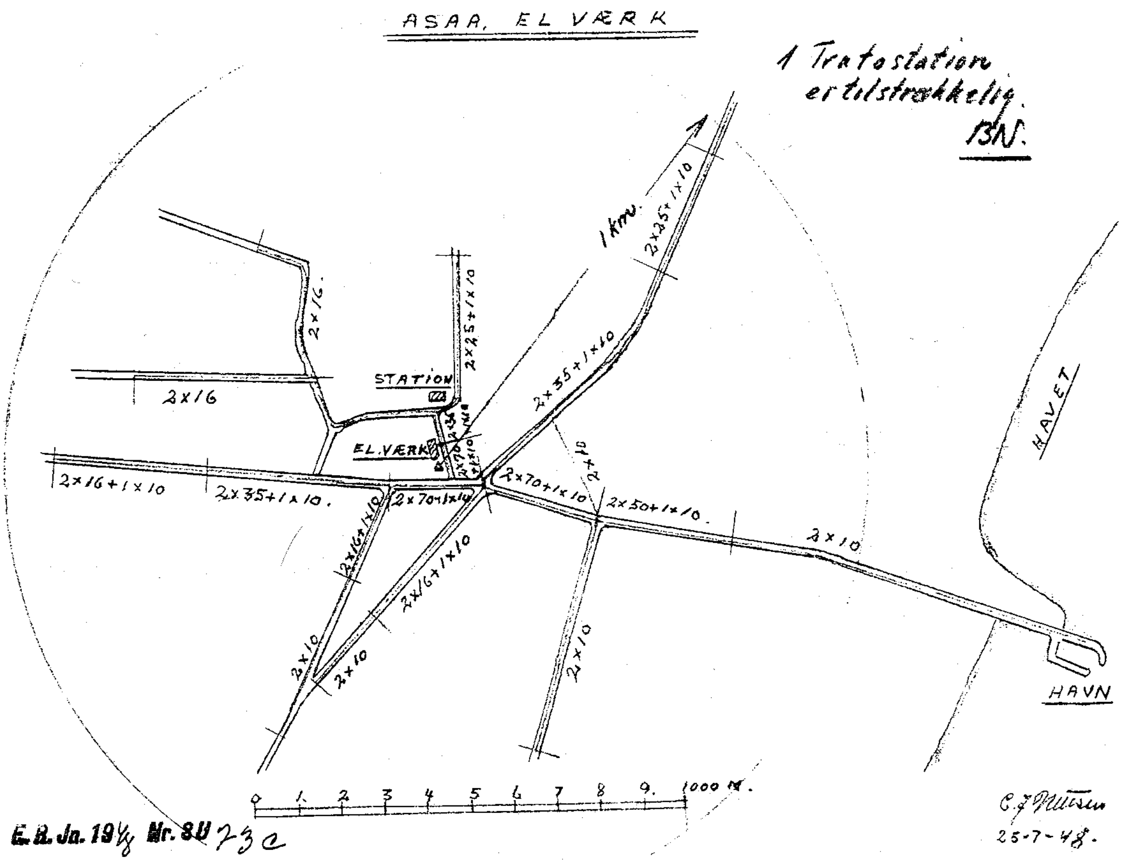


Figure 8.2: The local village system of Aså in 1948. The distribution lines follow the roads, and mostly stay within a kilometre from the power station. ['<u>El.Værk</u>' = power station; '<u>Station</u>' = train station; '<u>Havn</u>' = harbour; '<u>Havet</u>'= sea]. Source: National archives, Elektricitetsrådet, Samarbejdudvalget, nr. 73.

years ahead, by contrast, the Council calculated a modest advantage of just over a thousand krones for the purchase scheme. The Council therefore recommended electricity purchase on grounds of economy.

The utility, however, did not accept this calculation. Indeed, the margin to the advantage of the purchase scheme was rather small, and would almost disappear if the claim of the plant manager was recognized that the investment costs were merely nine thousand krones (saving 300 DKK annually), and if the Council had not included an extra 800 DKK for unexpected investments in the decentral expansion scheme. The Council was also accused for an overestimation of the demand and its choice of interest rates (writing off the diesel engine in merely fifteen years, but the high voltage equipment in twenty years). In the end, as the polemic C. E. Jensen wrote on behalf of the Aså utility, the utility decided to go ahead with its decentral expansion because 'this is the cheapest and most reliable' option. The utility insisted on its own calculations, which yielded an opposite result to the 'theoretical calculations' of the Council, relying on a better knowledge of local circumstances.[49] The Electricity Council then could do no more than publish its 'declaration' on the economic irrationality of this decision.

In a second expansion case in 1948, the Aså utility wished to expand its decentral capacity with a 86 kW diesel power unit. Again the Electricity Council contacted the Nørresundby municipal utility for an offer on supply, and this time it assessed three options; besides the schemes of decentral expansion of production capacity and full purchase of electricity, it included a scheme in which the current decentral production was maintained, but capacity was expanded by purchasing additional electricity through a converter. With regard to investment costs, the change to alternating current supply and purchase of all electricity was still by far the most expensive option. Yet the investment in conversion equipment was slightly lower than in a diesel power unit. As such equipment was also written off over twenty and partly twenty-five years, while the diesel power unit was written of over fifteen years, the annual fixed costs of the conversion scheme would be substantially lower. With regard to the annual costs in the middle year of 1951/52, the complete purchase scheme was clearly the most expensive, while the partial purchase scheme was slightly cheaper than the decentral expansion scheme. In addition to its calculation, the Electricity Council emphasised that alternating current supply should be introduced as quick as possible with an eye to future developments; it urged further negotiation between the Aså and Nørresundby utilities, for instance on the issue of economical support of the latter to the change of the Aså system to alternating current.[50]

Yet, the Aså utility did not desire to participate in such negotiations, and insisted again upon a decentral expansion. In a comment on this decision, the utility chairman

Table 8.3: Economical assessment of the expansion options for the Aså utility in 1936, 1948 and 1955.[51]

Year of expansion:	1936	1948	1955
Middle year in annual costs calculation:	1939	1951/52	1960
Option I: Expansion by diesel engine	DKK	DKK	DKK
Investment:			
Diesel power unit:	12.000 (23 kW)	58.000 (86 kW)	168.000 (175 kW)
Annual costs:			
(Sale/production in MWh):	(38.7/56)	(181/220)	(395/494)
Interest & repayment new loan:	1.100 (9.3%)	5.200 (8.99%)	22.800 (13.6%)
Interest & repayment old loan:	3.700	-	-
Wages:	2.350	9.000	12.500
Maintenance:	1.250	4.400	12.200
Fuel:	1.800	19.800	43.700
(pr. kWh sold):	(5 øre)	(11 øre)	(11 øre)
Rest:	3.300	5.100	16.000
Total:	**13.500**	**43.500**	**107.200**
(pr. kWh sold):	(35 øre)	(24 øre)	(27 øre)
Option II: Purchase all electricity			
Investment:			
Transmission line & transformer	:10.500	36.000	58.600
Change of distribution network, meters, installations, motors, radios etc to a.c.:	35.500	184.000	290.400
Sale power station (ground, building etc.):	-10.000	-45.000	-30.000
Total:	36.000	175.000	319.000
Annual costs:			
(Sale/purchase in MWh)*:	(38.7/42.7)	(181/200)	(395/494)
Interest & repayment new loan:	} 5.300	11.200 (6.4%)	25.000 (7.82%)
Interest & repayment old loan:		-	-
Maintenance:	1.250	1.000	1.000
Purchase electricity:	5.700	36.470	76.120
(pr. kWh sold)	(15 øre)	(20 øre)	(19 øre)
Rest:	-	6.030	11.200
Total:	**12.250**	**50.700**	**113.320**
(pr. kWh sold):	(32 øre)	(28 øre)	(29 øre)
Option III: Expansion by convertor			
Investment:			
Converter + transformer:		32.600	98.000
Transmission line:		20.000	28.000
Total:		52.600	126.000
Annual costs:			
(Sale/production/purchase in MWh):*		(181/196/19)	(395/214/317)
Interest & repayment:		3.700 (7.36/6.4%)	17.100 (13.6%)
Wages:		6.500	12.500
Maintenance:		4.100	11.200
Fuel:		18.800	18.900
Purchase electricity:		4.240	57.500
Rest:		3.660	14.000
Total:		**41.000**	**131.200**
(pr. kWh sold):		(23 øre)	(33 øre)

*Purchase is measured on the low voltage side of the transformer or convertor (apart from 1955, III). Transformer losses are thus excluded, distribution and meter losses included.

- a local smith - found the electricity prices of the purchase scheme 'rather illusory'; they were only estimates, and the calculation depended upon a ten years extrapolation in time - a period in which the situation could change radically. Moreover, at the decisive meeting of the general assembly of the utility, large consumers had insisted upon the argument of security of supply; in bad weather conditions high voltage transmission often broke down, and experiences from other villages showed that the current supplied was often 'very weak'. On this basis, the general assembly had opted for the decentral expansion scheme.[52] The Electricity Council then again wrote a 'declaration'.

Finally, the Aså utility applied for a third expansion in 1955. This time it applied for expansion with a 200 kW diesel power unit to meet its increasing demand. By then, the Nørresundby utility and other larger utilities in the Vendsyssel region had established the NEFO partnership for purchasing electricity from the very large power station in Ålborg (its capacity of some fifty-sixty megawatts was more than a hundred times as large as the 366 kW of the Aså village power plant after expansion), which was being integrated in the West- Denmark centralized system. It is therefore remarkable, that in this case the Electricity Council agreed with the decentral expansion, which it judged more economical for the Aså utility than connection to the centralized supply system.

Before applying for expansion, the utility had engaged the consulting engineering bureau Brix-Pedersen & Kamp Jørgensen in Ålborg to make an assessment of the different supply options, which it later send in to the Electricity Council and was largely accepted.[53] Notably, like the Electricity Council also the consulting engineers emphasised the qualitative advantages of alternating current supply: For the utility alternating current distribution would cause lower power losses and cheaper electricity meters (a 'major factor' in the utility economy), and for the consumers alternating current motors were cheaper and more reliable than direct current motors. Moreover, the increasing dominance of alternating current supply also made the market for direct current appliances smaller, and thus the prices higher compared to alternating current appliances. As we shall see in chapter ten, this became an important factor in the closing down of local systems.

From an economic point of view, however, they could not disqualify the decentral expansion option. With regard to investment costs, decentral expansion was again more expensive than a conversion scheme, but significantly cheaper than a transformer scheme. Yet as the alternating current equipment was written off in twenty-five years, and production and conversion equipment in merely ten years (with similar interest rates of six percent), the its annual fixed costs were not outrageously high. With regard to the annual variable costs, decentral production was much cheaper than the conversion scheme (which included purchase as well as fuel & wages), and also cheaper than the transformer scheme. In sum, the annual total costs in the middle year 1960 would be lowest in the decentral expansion scheme, slightly higher in the transformer scheme and substantially higher in the conversion scheme. Electricity purchase, then, was not necessarily economically superior to decentral production even in the mid 1950s, despite the proximity of the transmission network.

Given this economic assessment, several consumers at the general assembly made a case for alternating current supply. Among these were the chairman of the utility (now a carpenter), a local painter, an entrepreneur, a mechanic and a 'bus-owner'. For them, the consumer advantages of alternating current outweighed the slightly higher annual costs. On the other hand, the local slaughter and a farmer argued for the consolidation of direct current supply; their main objection to alternating current supply was the huge investment in new distribution network and consumer installations and appliances. In the ballot, about three-quarters of the 109 votes favoured direct current supply, and thus authorized the executive committee to carry though the decentral expansion.[54] As the executive committee found a significantly cheaper diesel engine than the one calculated with, and the savings of the utility covered most of this expense, it expected that the expansion would not be much of an economic burden for the utility.[55]

The consolidation arguments of small rural utilities

The central points of reference for maintaining decentral production in Aså, then, were economy and reliability of supply. If the Electricity Council doubted the economy of decentral production and therefore discouraged decentral expansion of production capacity, the Aså utility disqualified the conclusion of the Council, either by rejecting its calculations (in the 1930s) or by pointing at the insecure economic situation characterized by short contracts (in the 1940s). In such situations, economic certainty or the superior reliability of local systems proved a decisive advantage. The Aså utility, however, was but one out of several hundreds. In how far was the case representative?

The economic rationality of decentral production during the 1920s and 1930s

In the single rural utilities, the issue of decentral production vs. purchase of electricity might be put on the agenda, as soon as an expansion of supply capacity was needed. During the 1920s and 1930s, however, decentral production might be the only option and certainly often was the cheapest one. During the 1920s, large areas in Western and Northern Jutland simply were not yet covered by transmission grids. In this period, even some thirty-two new village systems were established.[56] Still, by the late 1920s the alternative options to expanding the decentral production capacity and continue operation in isolation from transmission networks were well known: By 1927, some twenty rural utilities had opted to supplement their decentral production with additional electricity purchase through a converter, while nearly sixty village systems had been shut down and and replaced by transformer stations in a larger system.[57]

Although the establishment of new village systems stagnated nearly completely in the next decade with merely eight new systems, by the late 1930s this preference for decentral production had hardly changed - despite the establishment of the Electricity Council. In the second half of the 1930s, merely thirty-six rural utilities did seek voluntary co-operation with larger utilities, twenty-seven of which fully shut down their decentral production of electricity. The large majority thus continued decentral production in complete isolation from the expanding transmission networks; moreover, a 157 small rural utilities operating local village systems applied for an expansion of decentral production capacity, and all but seven utilities indeed expanded their production capacity decentrally (table 8.4).

Table 8.4: Expansion cases of rural utilities treated by the Electricity Council 1935-1939. Source: Aubeck 1937, II; 1939, 350-351.

I. Applications for increased decentral production capacity:

	Number of applications	Approved immediately	Approved after negotiation	Utility accepts disapproval	Utility rejects disapproval
1935-37	67	34 (51%)	18 (27%)	1 (1%)	14 (21%)
1937-39	90	42 (48%)	22 (25%)	6 (4%)	20 (23%)
Total:	157	76 (48%)	40 (25%)	7 (4%)	34 (22%)

II. Voluntary co-operations:

	Expansion by converter (partial purchase)	Change to alternating current supply (complete purchase)
1935-37	3	11
1937-39	6	16
Total:	9	27

Surprisingly, the evaluation also shows that these decentral expansions most often were economically rational in the eyes of the Electricity Council. Thus, the Council could immediately approve about half of the proposed expansions, which means that its technical-economical assessments showed a superior economy - expressed in investment and annual expenses - of decentral production and expansion. Moreover, another quarter was approved after negotiations with the involved parties. In such cases, the economy of increased decentral production might be equal to that of electricity purchase, as for instance in the case of the proposed expansion of the small rural utility of Moseby on Falster in 1936. When the technical-economical assessment gave similar annual expenses for the decentral expansion and purchase scenarios, the Council drew attention to the technical advantages of alternating current supply under a larger system, and urged the parties to continue negotiations. In particular, it urged the Falster district utility - in the supply area of which Moseby was situated - to lower its electricity prices so as to make centralization feasible for the small utility. The general assembly of the Moseby utility insisted upon decentral expansion, however, which was thereafter approved of by the Council.[58]

Only for a quarter of the applications in the second half of the 1930s, the economic assessments led the council to disapprove of decentral expansion plans. This was before the rural utilities gained representation in the Council, and clearly contradicts the rhetorical claims of C. E. Jensen above that the Council 'always insisted upon centralized supply.' Still, it was in these cases that the tension between rural utilities and Electricity Council was manifest: As in the case of the Aså system, in such cases the applying utilities normaly held on to their own calculations and insisted - often through the associations of rural utilities - that decentral production was the cheapest option. An example similar to that of Aså is the claim of the rural utility in Lunde in Western Jutland in 1936, which notified the Electricity Council through C. E. Jensen that it 'could not accept the calculations of the Council, and regarded further discussion as pointless.'[59] Indeed, virtually no rural utilities did accept a negative verdict, nor doubted the economic superiority of rural local systems.

Decentral expansion after the Second World War

After the war, decentral expansion became increasingly unpopular, and an increasing number of small rural systems disappeared. Still, there remained a fair number of applications to the Electricity Council for decentral expansion in the 1950s, and even a few in the 1960s. The arguments of economic and technical superiority were still frequently heard: Vilhelm Mondrup explained the economic feasibility of decentral production with reference to the combination of relatively high electricity prices demanded by transmission companies, and low diesel oil prices.[60]

In a number of cases, like in the expansion of the Aså system in the mid 1950s, decentral expansion was judged economically rational. In case of a proposed expansion of the local village system in Faster in Western Jutland in 1956, for instance, the assessment of the Electricity Council showed that a change to alternating current supply was the most expensive option, the combination of decentral production with additional purchase some seven percent cheaper, and increased decentral production some nine percent cheaper. The margins were thus small, but to the advantage of decentral expansion, despite the fact that the purchased electricity would be produced on the large power plant in Esbjerg in the centralized system: With a capacity of some sixty megawatts, the latter was more than two-hundred times as large as the 285 kilowatts power station in Faster after the expansion. Still, the Electricity Council had no choice but to approve of the decentral expansion.[61] Another example is the rural utility in Radsted on Lolland, which in 1949 decided for a decentral expansion, despite the fact that it already had a connection to the transmission grid of the Falster district utility on the East Danish centralized system. Yet the price at which additional electricity was purchased was slightly higher than the price at which electricity was sold to the consumers (18 kWh/øre vs.15 øre/kWh); Moreover, additional electricity was not available during the peak demand in the threshing season. Negotiations with the Falster district utility on lower prices failed, which was why the general assembly accepted the decentral expansion with a new diesel engine.[62] Finally, an example of a decentral expansion, which according to the Electricity Council was 'unambiguously favourable' for a small rural utility as late as 1964, was the case of the local system in Uglev in North-Western Jutland.[63] The Council attributed this economic feasibility of decentral expansion partly to the very cheap offer on a used diesel engine, and partly to the relatively high tariffs of the rural district utility of Thy [*Thy Højspændingsværk*], in the supply area of which Uglev was situated, despite the fact that also the Thy utility received its electricity from the very large power station in Esbjerg.

In other cases, there might be a small economic advantage for electricity purchase, but consumer preferences resulted in the decision to expand the decentral production capacity. An example is the proposed expansion of the power station in Jelling, a village (by now a small town) in the supply area of a district utility in the hinterland of Horsens, in the mid 1950s. Despite the fact that the district utility received its electricity from the very large power station near Fredericia (with a capacity of 127 megawatts, or some two-hundred times as large as the 620 kilowatts power station in Jelling after expansion), the change to alternating current supply showed only a small economical advantage of about five percent on annual expenses. The wish of the consumers to preserve direct current supply and the bad relations with the district utility then motivated a decentral expansion.[64]

Finally, it is noteworthy that there might be disagreement among the consumers, and in such cases a ballot at the general assembly was decisive. For instance, the majority of the general assembly of the village utility in Søndersø on Funen in 1954 voted in favour of decentral expansion, against the proposals of its executive board, which in view of similar annual costs for the different expansion options would prefer a change to alternating current supply bought from the very large power station in Odense.[65] Notably, the closing down of a local system often required a large majority of two-thirds or even three-quarters of the votes according to the statutes of co-operative societies. In such cases, even a minority of consumers could prevent the shut down of the local system.

Connection and decentral production

Finally, although decentral expansions of production capacity became more rare during the 1950s, this did not necessarily mean that decentral production was abolished. Like municipal utilities, also rural utilities might actively use the modern technical possibilities of connection, while at the same time preserving their decentral production. While decentral municipal utilities often actually co-operated on interconnections, however, rural utilities used the technology of connection merely to purchase additional electricity. It was this combination of decentral production with purchase of electricity, that was embodied in the above option to expand with a converter.

Sometimes, such connections were merely used for backup. As the decentral back-up systems in the form of batteries remained rather expensive in maintenance, back-up through a converter might be attractive. Indeed, spokesmen of rural utility associations praised the option of converters in a back-up function. Mondrup, for instance, emphasised that even though the Electricity Council often recommended expansion by a converter, it still placed the bulk of supply on the decentral production machinery in its assessments, and thus in effect recommended to use the converter merely for back-up. The advantage of a converter in this function was its low investment and thus a reduction of annual fixed costs. Yet, Mondrup contended, due to the high electricity prices of large scale systems, supply from a converter would be too expensive in the long run if decentral production lacked.[66] A similar point was made by the chairman of the association of rural utilities on Funen, who saw additional purchase through a converter as a means to increase the reliability of electricity supply, while at the same time preserving decentral production.[67]

Indeed, the rural utilities often combined decentral production with purchase through converters. It was mentioned above that during the fuel shortages of the Second World War, some hundred rural utilities connected to transmission networks. By 1950, eighty-seven out of some two hundred and thirty remaining local village systems (including only those in villages with less than a thousand inhabitants) had one or more converters to purchase electricity. Notably, these utilities used their converters more than simply for back-up, and might purchase a substantial part of their daily electricity supply. A sample from the Ringkøbing county in Western Jutland shows, that eleven out of thirty-two local village systems purchased additional electricity. Of these utilities, only one village utility used its converter rarely, purchasing merely two percent of its electricity. Five utilities produced substantially more electricity decentrally than they purchased, while three utilities purchased amounts of electricity similar to their decentral production. The remaining two systems purchased more than they produced. Together, these eleven utilities purchased about one third of their demand.[68]

By 1960, forty-two out of some ninety remaining rural local systems received additional power through a converter. At this time, however, many other rural utilities purchased additional electricity as part of a gradual transition to full alternating current supply; in a transition phase, they might purchase electricity directly from transformers and supply part of their supply area with alternating current. At that time, less than thirty small rural utilities maintained decentral production in complete isolation from transmission grids.[69]

Favourable conditions for decentral production: The few cases of CHP, hydropower and island systems

CHP production in small towns

Like in the case of decentral town systems, there was a (relatively small) number of decentral rural systems that remained feasible due to particular circumstances. First, it is remarkable that some of the rural utilities in small towns adopted combined heat and power production. Indeed, this option had incidentally been praised by spokesmen of rural utility associations as a way for their larger members to improve the economy of decentral production. And in some cases, the argument of CHP production was actually used to justify a decentral expansion of production capacity. For instance, after the Electricity Council disapproved of the proposed decentral expansion of the system in Tarm in Jutland in 1947, the co-operatively owned utility replied that it must insist upon this expansion, as it planned to take up CHP production. Planning to supply heat to a nearby home for the aged, several municipal offices, a co-operative laundry, a public bath and a school, it expected 'good profits' of such an arrangement; indeed, it even claimed that the investment in an new engine could be repaid solely by the income from heat sales.[70]

Likewise, the co-operatively owned utilities in the small Jutland towns of Ikast and Grindsted, both with about four thousand inhabitants by 1950, adopted town heating after the Second World War. The Ikast utility had supplied waste heat from its diesel engine to the greenhouses of a nearby market-garden since the mid 1930s, but extended its heating system to regular town heating after the war; the cooling water from its diesel engines was insufficient, however, and the heat supply was to a large extend based upon heat boilers. The Grindsted utility took up town heating from 1950, after a calculation had shown that large annual sales would return the investment in about four years.[71] As the heat demand rapidly grew, however, these small utilities chose to expand their heat capacity with boilers for pure heat production. When they were absorbed in the centralized system during the 1950s, they abandoned their CHP units, and only maintained pure heat stations. In sum, CHP seems not to have had a significant impact on the consolidation of decentral rural systems.

Hydro-powered rural district systems

Second, a number of small hydro-powered rural systems were maintained. These included most of the rural district systems; although their number only constituted a small fraction of that of local systems, these had a disproportionally large electricity output up to half of that of local systems. Often, the district system had been established in the first place to exploit the available hydropower resources, all rather small, and all situated in Western Denmark. The often consumer-owned utilities exploiting such systems were no members of the various associations of rural utilities; in all circumstances, their situation was too different to apply the same reasoning.

Still, small hydropower district systems often remained economically feasible, as they were characterized by relatively high establishment costs but very low running costs. This is perhaps best illustrated by the fact, that most such rural utilities joined centralized systems, but simultaneously chose to maintain their decentral hydropower production, even though this decentral production in time became insignificant relative to the amount of electricity obtained from the centralized system. In this, they resembled the hydropower plants operated by several municipalities mentioned in the previous chapter. For instance, the Mid-Jutland Electricity company MES, described in chapter four, expanded with hydro-turbines and diesel power units during the interwar period; during the Second World War and the lack of diesel oil, however, it chose to connect to the South-Eastern Jutland Interconnection to purchase additional electricity. At the end of the war, the MES utility even decided to become a partner in the centralized system under construction. When the latter became operational in the early 1950s, it shut down its diesel power units, but maintained its hydropower production. Producing 500-600 MWh annually, however, the decentrally produced share of its supply became very small relative to the energy obtained from the centralized system, and was in 1960 only three percent.[72]

A similar solution was preferred by the Horsens hinterland rural district utility, which also joined the centralized system as a partner, but maintained its decentral production of hydropower at Vestbirk (2 GWh annually). Others, like the rural district system based in Brande near MES, did not join the centralized system, but bought additional electricity while maintaining its decentral hydropower and diesel system (500 MWh), which completely overshadowed its decentral production. A different case is the hydro and diesel power system Brende mølle on Funen (mostly diesel), a small rural district system which even in 1970 decentrally produced some thirty percent of its annual demand of seven gigawatthours.[73]

Island systems

Finally, a small but particular group of small rural utilities were those situated on some of the many (more than four hundred, eighty of which inhabited) small Danish islands. Contrary to the case of Bornholm described in the previous chapter, supply often could be realized from the mainland or from large islands nearby fairly easy by means of a relatively short submarine cable. The number of independent island systems was therefore marginal. However, as purchase demanded a submarine cable and therefore was more expensive and unreliable than for utilities on the mainland or on the large islands, a number of small island communities did choose to maintain their own decentral systems up to the 1970s. Notably, several island communities even decided to establish new decentral systems after the Second World War; this included systems on Anholt (1949), Christiansø (1949), Mandø (1952), Tunø (1954), Aksø (1956) and Læsø (1962).[74]

During the 1960s, several island utilities opted for decentral expansion. An example is the system on Strynø near Langeland, which dated from 1915, and supplied less than two hundred consumers. In the mid 1960s, the local utility found the option of supply from Langeland and conversion to alternating current too expensive; the costs of the three kilometres submarine cable were said to make the difference.[75] Another example is the failed attempt to supply the small village systems on the islands of Fejø, Femø, Lillø and Askø North of Lolland in the first half of the 1960s. These island systems were now situated in the supply area of the large South-Eastern Zealand district utility SEAS, and could be supplied jointly by means of a submarine transmission ring. Yet the general assembly of the largest island utility, that on Fejø, univocally opted for a decentral expansion; although the island was situated merely 2.5 kms from the coast of Lolland, the assessment of the Electricity Council showed that decentral expansion of the local system clearly gave the lowest annual expenses - provided that the costs of changing the distribution network and consumer installations and appliances to alternating current were included in the purchase scheme. The consumers then argued that as long as televisions and refrigerators for direct current were available, they were satisfied with their local system. This decision, in turn, made transmission to the other islands unfeasible: Askø and Femø thus maintained or expanded their systems, while Lillø remained unelectrified.[76]

The actor group of consumer associations, then, mostly justified the consolidation of decentral rural systems with reference to their economical and technical performance, which they often found superior to that of larger scale systems. This corresponded to the arguments of their spokesmen, who criticised 'local patriotism' in the sense of stubborn opposition to new technology or to central actors, but insisted upon the 'local autonomy' for small utilities to choose the cheapest and most reliable supply option. Until the 1950s, these criteria of judgement led to the massive consolidation of small rural local systems: And as the calculations of the Electricity Council, the instance closest to an objective observer on the economical assessments, show, even the decentral expansions of small local village systems were often economically rational, or at least not decidedly irrational. In the 1950s and 1960s this still might apply, but by 1970 only few systems remained, and here special circumstances applied: Of the thirteen remaining decentral rural systems, five of these were district systems running on small hydropower stations, while only one district system run on a small diesel power station (the village system of Nørreherred pr. Voldby in Jutland). The remaining seven systems were local systems on the islands of Anholt, Tunø, Endelave, Mandø, Strynø, Askø and Christiansø.[77]

Part III

The success of centralized supply in the post-war period

9

The municipalities and the completion of the centralized system

While the municipalities of Danish provincial towns generally had insisted upon the consolidation of their decentral local or district electricity supply systems in the 1930s and 1940s, in the following decades they massively opted for purchase from the centralized electricity supply system. By 1970, only eight decentral town systems remained. After a brief survey of the context of this development, the rapid increase of the electricity demand for in the post war period, this chapter first examines the further development of the East-Danish centralized system by its traditional actor group of large utilities - prior to the involvement of the municipalities. Then it regards the developments in Western Denmark, where some medium-sized municipalities invented and a sociotechnical model for building a West-Danish centralized supply system during the 1940s, which took into account the concerns of such municipalities. This model was largely implemented In the region in the late 1940s and early 1950s. Then focus is again shifted to Eastern Denmark, where the municipalities sought integration in the centralized system after West-Danish example. Finally, the role of technical problems stemming from direct current supply - both in municipal local and district systems - in this development is briefly addressed.

The context of centralization: The growth of demand

The context for the dynamics of the different electricity supply systems and their mutual competition in the post war period was a huge increase of electricity consumption in the supply areas of the single utility. Also in the interwar period electricity consumption had increased rapidly, with nearly a factor five in the 1920s and 1930s. Still, Wistoft (1994) characterized this growth as one of 'broad covering and low consumption', meaning that it resulted from the spreading of electricity through Danish society, while the average consumption per inhabitant remained comparatively low.[1] Thus, by 1940 some ninety-eight percent of the Danish households in urban municipalities had access to electricity, while the figure for rural municipalities was seventy-five percent, and the national average eighty-seven percent.[2] Yet, the average electricity consumption per inhabitant in Denmark was among the lowest in Europe, despite the fact that Denmark had one of the highest gross national products per capita. For instance, although Denmark had a slightly higher GNP per head than Germany and the United Kingdom, its electricity consumption per head was only half. Moreover, the Danish electricity consumption was relatively lower than that in countries with a significantly lower GNP per capita, such as the Netherlands, Austria and Italy. In fact, Denmark had the lowest pr. capita electricity consumption in Europe with the exception of Ireland, Greece, Portugal and Turkey. This made the contrast to its Nordic neighbours, which had turned their cheap hydropower resources into the primary energy source, only larger: Despite a similar GNP per head, Sweden's electricity consumption per head surpassed that of Denmark by a factor four, Norway's - the highest in the world - by a factor eleven.[3] By 1950 this relative position had not changed. The statistics of the OECD also show why: On one hand, the Danish consumption pr. head for lighting, domestic uses, trade, handicraft and agriculture was relatively high - the highest in Europe shortly after the Netherlands, if the hydropower countries (Norway, Sweden, Iceland and Switzerland) and the United Kingdom are excluded. On the other hand, although the electricity consumption in Danish industry was of the same order of maginitude as that of households and agriculture, it was marginal relative to that of other European countries - a factor 2-3 lower per. inhabitant than in for instance Germany, Belgium, the Netherlands, Austria and France.[4]

Although electricity had been made available in most of the country, then, there was room for an increase in electricity demand in the post war period. Indeed, electricity consumption increased even faster than in the rest of Europe, and at an even higher rate than in the interwar period: During the 1950s and 1960s, the gross production of electricity in Denmark (incl. net imports and autoproduction) increased further by a factor seven - from 2.6 gigawatt-hours to 14.6 gigawatt-hours annually - or from 484 to 2648 kilowatt-hours per inhabitant.[5] This development coincided with a boom of the economy in the post war period, with a ten-fold of the gross national product between 1939 and 1967.[6] This included a rapid growth of industry; although industrialization had started in the first half of the 19th century and a Rostowian 'take off' has been observed in the 1890s, it was first in the post war period that the industrial sector became by far the largest one in terms of employment.[7] Moreover, the dominance of heavy industry was relieved by a broad spectre of light industries - not in the least producing consumer goods. In addition to the growth of industry, the tertiary sector grew to account for about half of the Danish GNP since the 1930s. Finally, even though the production value of primary sector grew by a factor five, its relative share of the Danish GNP was halfed to a modest 10% in the late 1960s

Coinciding with this growth and restructuring of the economy, the post war period markes a rapid increase in industrial electricity consumption and an even faster increase in that of households and commerce. While industry rapidly electrified[8], electricity consumption in households followed the emergence of a consumer society, which also in Denmark was inspired by the 'American way of life': While electricity previously was used for lighting and in a lesser degree for heating, this included the massive introduction of electric refrigerators, stoves, washing machines and televisions. For instance although refrigerators had been introduced in the 1920s and 1930s, merely 6.5% of Danish households had one by the early 1950s. In addition, there was an increasing number of collective 'freezer houses'. Yet by 1970 individual households had massively adopted domestic cooling machines: 80% had a refrigerator, and 40% a deep freezer. By then, also some 40% had an electric washing machine, which were particularly popular in the massively build detached houses. Finally, although television transmission was first introduced in the first half of the 1950s, the television proved the electric appliance with the highest diffusion rate of all - by the mid 1960s covering 75% of the Danish households. As a result of these developments, by 1970 the Danish electricity consumption per head had surpassed that of the Southern European countries, and approached that of France, the Netherlands and Germany. As Wistoft. et. al. (1992) put it, Denmark had made the transition from 'developing country to industrialized country' on the field of electricity supply.[9]

The East-Danish Centralized system 1940-1953

Three production companies and their power stations

In chapter five it was described, how a handful of the largest utilities in Eastern Denmark had build a centralized electricity supply system by the beginning of the Second World War. A fifty kilovolts power grid covered most of the area - that is, primarily the large islands of Zealand and Falster, while supply of the grid had been concentrated in the very large power plant of the municipal utility of Copenhagen and the hydropower link to Sweden, owned by the Northern Zealand utility NESA. Other participants, like the supply companies of North-Western Zealand NVE, South-Eastern Zealand SEAS and Falster FH had become transmission companies purchasing their electricity from NESA, while the large municipal utility of Frederiksberg maintained some decentral electricity production.

Prior to 1953, the middle-sized and smaller municipalities in the region were not directly involved in the operation of the centralized system. Still, the large utilities participating in the system expanded its capacity considerably during and after the War, involving both technical and organisational constructions, in order to anticipate the rapid growth in electricity consumption. Technically, this resulted in the establishment of new very large power stations in Kyndby at the Isefjord (1940), on the small island of Masnedø just off the Southern Zealand coast (1940), and a second large power station in Copenhagen (1953). Organisationally, the centralized system was run by three large production companies on the basis of a mutual agreement of cooperation (figure 9.1).

The initiative for the first expansion of the system was taken by NESA, which by the mid 1930s could calculate by extrapolation that the Copenhagen power plant - which was already fully extended - would not be able to supply the entire East-Danish region after the contract between NESA and Copenhagen expired in 1940.[10] The company then investigated where a new power station should be situated, and already in 1935 purchased some land for this purpose near the Isefjord in Northern Zealand. Besides cheap land, the location offered direct sea access through the fjord (and thus access to cheap coal by ship) and lacked civil habitation (and thus of complains of fly ash).[11] The year after NESA started negotiations with the other buyers of Copenhagen electricity NVE, SEAS and Frederiksberg to commonly finance the establishment of a new power station on its newly acquired land. An alternative proposal from Copenhagen to extend its production capacity (by replacing an old turbine with a new 30 MW unit, or by building a new Copenhagen power station) was rejected, although it had the sympathy from SEAS.[12]

The organisational result was the establishment of a new production company, the partnership *Isefjordsværket* (IFV), in 1937. The company was established by NESA, NVE and the Frederiksberg utility, and was to obtain electricity for its partners. These, in turn, continued their existence as distribution companies. The IFV company then built, owned and operated the new power station at the Isefjord, which was inaugurated in 1940 with a capacity of sixty megawatts, and was interconnected in the East-Danish grid with fifty kilovolts lines to the Kamstrup junction and to NESA's central transformer station and dispatch centre Ørnegården. In addition, the partnership took over the administration of the concession on Swedish hydropower from NESA. In practice, however, NESA dominated the new company; it both appointed the chairman of the board of directors and stood for the administration and operation of the new company from its dispatch centre. First in 1955 the partnership would obtain its own administration, but under common direction with that of NESA.[13]

The SEAS company, however, had withdrawn from the negotiations, and build its own large power station in the South. According to SEAS director Kaj Ørum, the IFV power station was situated too far North to supply the entire SEAS supply area through the fifty kilovolts power grid, and the other partners refused to participate in the financing of a new transport line of higher capacity. Moreover, when SEAS left the negotiations with the intention still to buy IFV power as long as possible, the IFV partnership increased its electricity price of future electricity sales to SEAS. SEAS then decided to build its own power station on the small Masnedø island in the centre of its supply area. The new fifty megawatts power station was built in two years, and was also operational in 1940; it was connected to the Zealand grid by three 50 kV cables.[14]

Finally, also the municipal power company of Copenhagen built a new large power station to meet its increasing demand. The construction of this power station had been planned in the 1930s, but had been postponed due to the construction of the power stations of IFV and SEAS, which reduced the market for the Copenhagen utility considerably. After the Second World War the issue was again taken up, and a new power station was inaugurated in 1953.[15]

Co-operation on the grid

The construction of new power stations and actors, of course, meant that the organisational structure for co-operation had to be adapted. The production companies IFV and SEAS established a tight economical co-operation on a voluntary basis.[16] During the war, they had agreed on a limited co-operation; whereas they in principle should supply their own supply areas, they agreed to use the power grid to provide mutual back-up in case of failures, and possibly exchange additional energy, meaning that supplied electricity was to be returned. Yet due to the specific situation of the Second World War, where the traditional (grate) boilers of the SEAS company were easier adapted to burn indigenous lignite than the advanced powder coal injection boilers of the IFV power station, SEAS sold considerable amounts of electricity to the IFV partnership.[17]

Immediately after the war, the parties agreed on a more tight economic co-operation. In a 1946 contract they agreed to operate the two power stations and the available Swedish hydropower imports in parallel in order to achieve the best common economy - although on a voluntary basis. The agreement - known as the IFV/SEAS co-operation ['*samkøring*'] - thus created a new actor with regard to running the system, but retained two independent actors with regard to ownership (and the decision of operation and expansion) of the power stations. The co-operation was coordinated by the IFV company and thus from the NESA control centre. In its daily scheduling of the production of the SEAS and IFV power plants, it would first seek to use all available hydropower from Sweden. Then it would plan the production of the SEAS power station. If SEAS agreed to its production scheme, which it usually did, the energy trade with the Copenhagen utility was included, and finally the production of the IFV power plant determined. This procedure should enable an optimal exploitation of the available resources: On one hand, it facilitated quick response to the fluctuations in available cheap Swedish hydropower. And on the other hand, it facilitated an optimal production economy in the two power stations in the IFV/SEAS co-operation: The load of the SEAS power station was kept as steady as possible, while the IFV power station with its quickly adjustable powdered coal boilers was used to absorb fluctuations in the demand.

The IFV/SEAS co-operation also acted as a partner towards the third producing actor on the system, the municipal supply company of Copenhagen. Before the second half of the 1960s, the co-operation between IFV/SEAS and the Copenhagen utility involved only the trade of additional energy. Each party in principal produced the electricity necessary to supply its own supply area, and additional energy exchange took place if it was economically attractive.[18] In practice, particularly from the early 1950s Copenhagen increasingly bought additional energy from the IFV/SEAS co-operation, which not only had access to hydropower, but also a better production economy in its continuously modernized thermal power stations.[19]

Planning a West-Danish centralized system

Also described in chapter five, in Western Denmark the attempts of large actors to establish a centralized system covering all or most of the region before the Second World War had failed. By 1940 the diffusion of centralized supply remained limited to the area of the large Southern Jutland utility, which had connected its large power station to the power grid of Northern Germany, and the Mid-Jutland area supplied by the large municipal utility of Århus and the Gudenaacentralen partnership, in which production was concentrated in the large Århus thermal power station and Denmark's largest hydropower station, interconnected on a fifty kilovolts grid. In addition, there existed some interconnections which facilitated co-operation between a number of medium-sized municipal utilities. Yet instead of using the technology of interconnection to concentrate the production of electricity in the largest possible power stations, these utilities preferred to use interconnection merely to improve the performance of their decentral systems - an arrangement which in chapter seven was termed 'decentral co-operation'. When the oil shortages of the Second World War motivated the different actors in the area to construct a West-Danish sixty kilovolts power grid, this model of 'decentral co-operation' was adopted by medium-sized and smaller municipal utilities in most of the region: Although wartime diesel oil shortages necessitated electricity purchase from the large actors in the system, the municipalities saw this merely as a temporary arrangement, and strongly opposed to a permanent role as purchasers of electricity.

Immediately after the war, however, the sub-committee of the government 'Electricity Commission of 1941' again produced a vision on the rationalisation of West-Danish electricity supply. The background for the establishment of this commission was a the work of another government committee, the 'Commission of production and raw materials' appointed by the Prime Minister's Department to investigate the Danish energy supply situation (electricity, heat, cokes, gas and refined oil). In its report published after the Occupation in 1940, this committee made a strong case for centralized electricity supply: It primarily referred to the importance of cheap power supply to industry, which should stimulate the industrialization process and thereby increase employment in the industrial sector.[20] Yet this committee did not represent electrotechnical expertise at all, and therefore recommended the establishment of a more qualified committee to design both a concrete centralized electricity supply scheme, and investigate the means to establish it. This resulted in the appointment of the 'Electricity Commission of 1941' under the Ministry of Public Works.

Yet as briefly mentioned in chapter five, this commission never actually met during the war, and was dissolved before it could discuss the means to introduce centralized supply, for instance by expanding the legal competence of the Electricity Council. Still, its technical sub-committee was invited to continue its study of the most economical arrangement of supply. Notably, besides two professors in electrotechnical engineering, the sub-committee included the directors or chief engineers from largest utilities in the country, which already were committed to configuration of centralized electricity supply: Eastern Denmark was represented by the Copenhagen municipal utility, NESA and NVE, while Western Denmark was represented by the Southern Jutland utility and the Århus municipal utility. When the NVE representative died during the war, he was replaced by a representative from the large Odense municipal utility.[21]

The 1946 report of the sub-committee, then, investigated the most economical degree of concentration of electricity production; moreover, it was to consider the influence of co-production of heat and power on the economy of centralized electricity supply. For as mentioned in chapter seven, such co-production of electricity and heat for district heating had been mobilized as an argument for maintaining decentral electricity production in middle-sized towns. Finally, the committee selected the Western Denmark region as its object of study, since in Eastern Denmark a centralized system already existed.[22]

With regard to the degree of concentration of production in Western Denmark, the committee proposed a concentration of production in six very large power stations - in addition to six quite small hydropower stations. These should be situated in the main load centres of Ålborg, Århus, Fredericia, Esbjerg, Åbenrå and Odense (figure 9.2). It had also investigated a scheme, in which production would be concentrated in merely two power stations. This would result in slightly lower costs of electricity production. However, it would also involve disproportionally large investment costs: For while the former scheme could use the existing sixty kilovolts grid, the latter

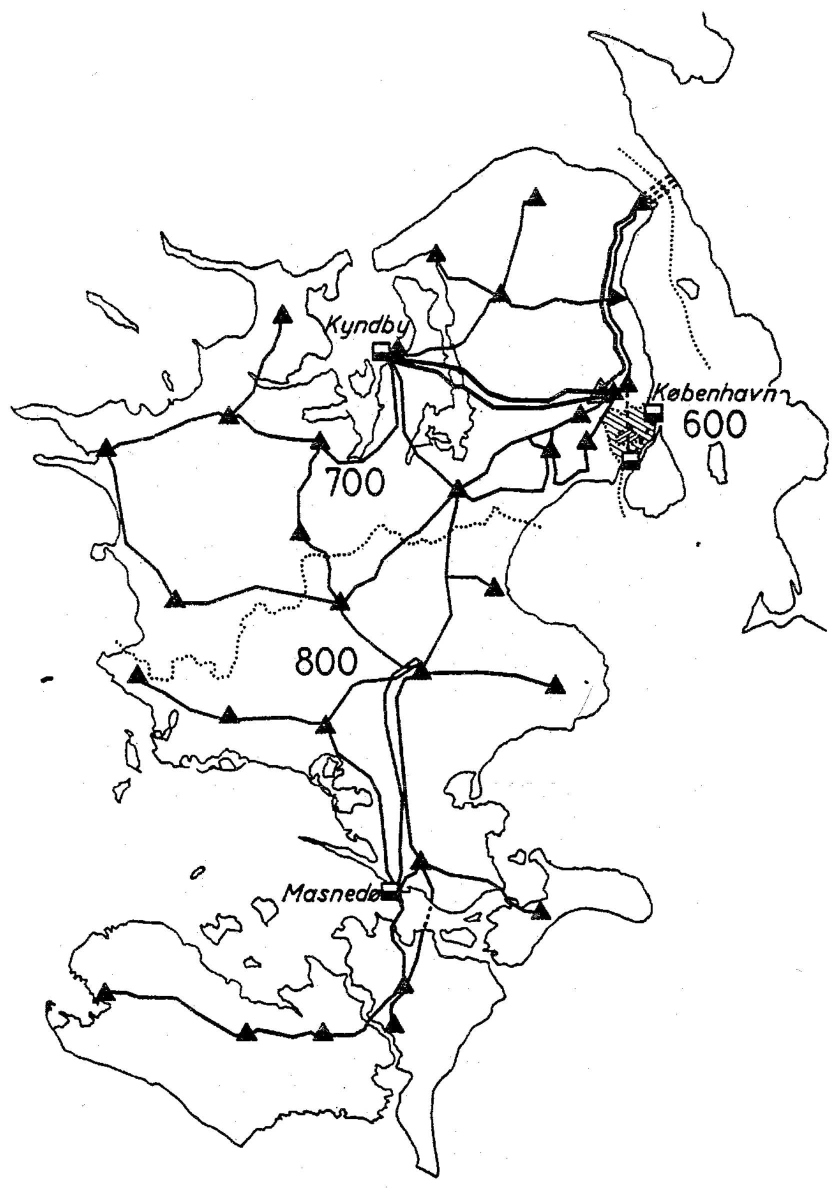


Figure 9.1: The East-Danish centralized system in 1954.The 50 kV grid is fed by primary power stations at Kyndby (222 MW), Masnedø (90 MW) and Copenhagen (133 MW and 48 MW) besides Swedish hydropower imports. Source: Det Statistiske Departement 1956.

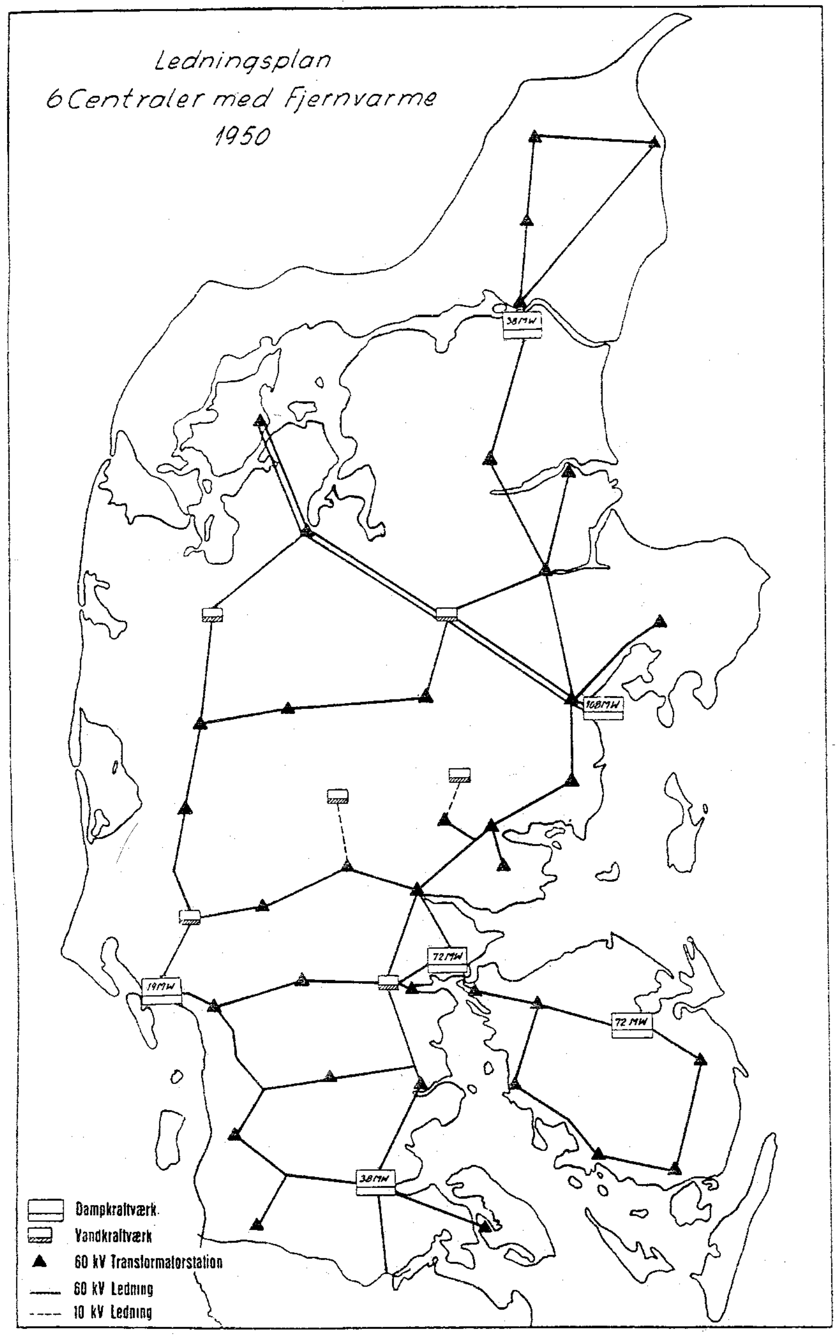


Figure 9.2: The centralized supply scheme for Western Denmark (including district heating) proposed by the technical subcommittee of the Electricity Commission of 1941. The large power stations represent steam power stations, the small ones represent very small hydropower stations. Source: Elektricitetskommissionen af 1941. Teknisk Underudvalg ... 1946, appendix 3.

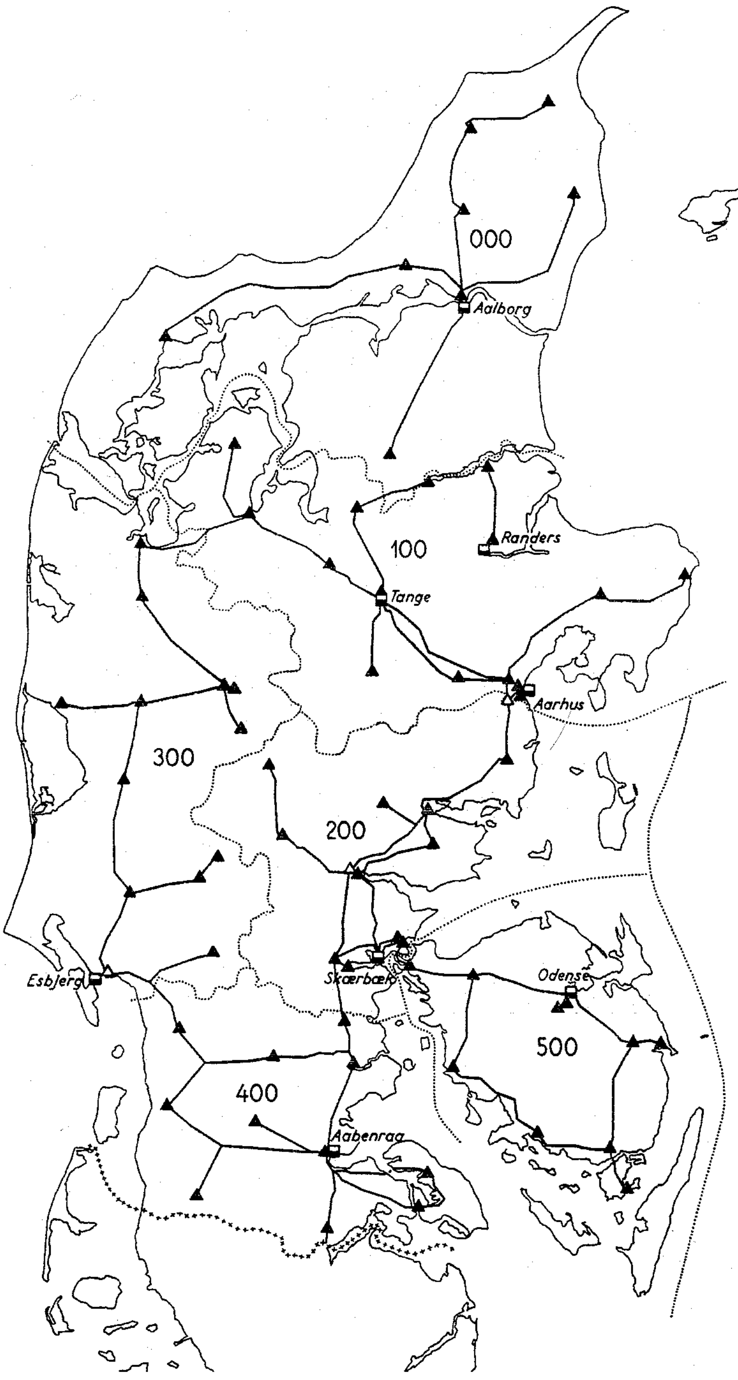


Figure 9.3: The West-Danish centralized system and the supply areas of the participating production companies in 1954. The system included a 60 kV power grid and primary power stations at Åbenrå (75 MW), Skærbæk (65 MW), Esbjerg (60 MW), Odense (82 MW) and Århus (105 MW). Also the relatively small hydropower station at Tange (3.6 MW) was interconnected. Source: Det Statistiske Department 1956.

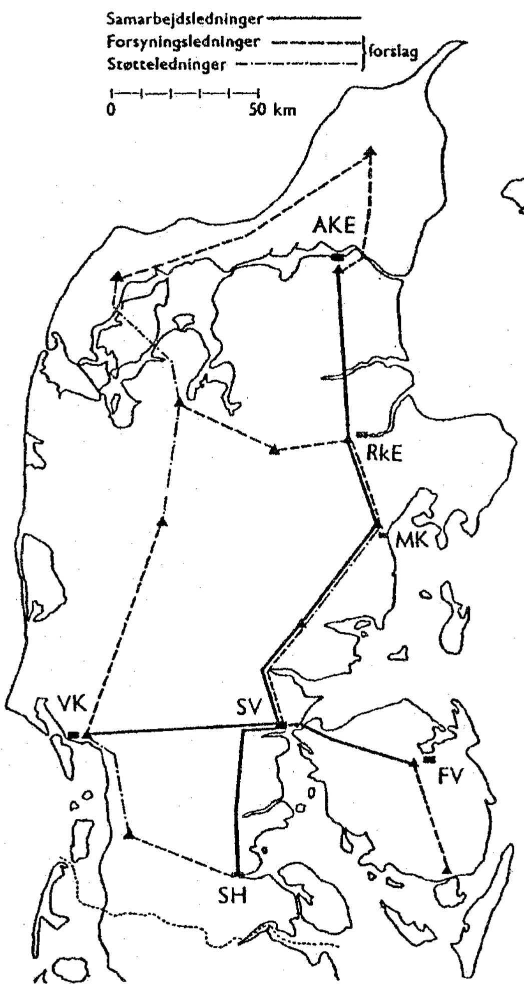


Figure 9.4: The 150 kV power grid and the primary power stations of the West-Danish centralized system around 1960. The 'cross' of interconnections as well as the transmission line Vestkraft-Herning had been built. Source: Jakobsen 1957

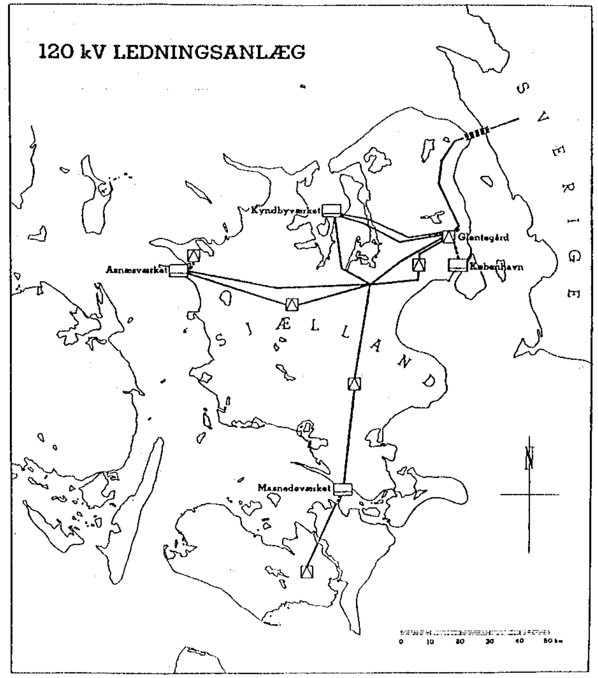


Figure 9.5: The power stations and 120 kV power grid of the East-Danish centralized electricity supply system in 1960. Source: Brodersen 1959, 7.

scheme presupposed the construction of a new power grid, operated at for instance one hundred and twenty kilovolts, to facilitate electricity transport over much larger distances.[23]

According to the calculations of the committee, the inclusion of CHP production did not affect the economic superiority of a scheme with six power stations. According to these calculations, it would be economically feasible to use CHP in the large power stations of the four largest towns Ålborg, Århus, Esbjerg and Odense (the latter three in fact already used CHP), as the higher investment costs of CHP equipment were more than outweighed by the income from heat sales. It would also be feasible to situate the East-Jutland power station in Vejle instead of the smaller town of Fredericia and use CHP. On the other hand, several schemes of CHP production in smaller towns (such as Fredericia, Kolding, Vejle, Horsens and Randers), which thus entailed a relative decentralisation of electricity supply, was found economically unfeasible relative to a scheme of centralized electricity supply.[24] The commission therefore strongly opposed to such an arrangement, concluding that CHP production was economically feasible only, if electricity production was not decentralised.[25] Yet it acknowledged that the situation was different for autoproducers: Although the variety of factors demanded individual assessment of each single case, here decentral CHP production might well be feasible - particularly if district heating was not available.[26]

The model of joint municipal ownership

It has been suggested that the 1946 report was more or less responsible for the development of a West-Danish centralized system in the decade after the Second World War.[27] Indeed, when established, this system did closely resemble its recommendations. However, it is important to notice that the large actors involved in the writing of the report - that is, the large utilities of Århus, Odense and Southern Jutland - did not have primary agency in the final consensus of the centralized supply system. As before the war, these actors were unable to enroll the medium-sized and smaller municipal utilities in their plans. This latter group still resented the idea of centralized supply dominated by few large utilities, and might indeed reject the work of the government committee, for instance by pointing at the 'idealized' character of the study; the calculations neglected investments that had already been made, and thus could not account for the factual economic feasibility of for instance the Randers CHP plant.

Instead, the initiative to make the transition from decentral to centralized supply stemmed from middle-sized municipalities, and would end as a joint project of large, middle-sized and smaller urban municipalities as well as larger rural companies. As co-author, professor Robert Henriksen could observe in a presentation of the government report, this actor group was already working in the direction recommended by the report prior to the work of the government committee.[28] He could also observe that this project was tied up with an organisational model of joint municipal ownership of large-scale production facilities, in a similar way that the Southern Jutland utility and also the IFV utility in Eastern Denmark were owned by distribution companies. This model maintained municipal control with the means of production, and should combine the advantages of concentration of production with those of decentral ownership and control with the distribution of electricity. We can speak, therefore, of a sociotechnical construction with interrelated technical and organisational components, which finally facilitated the emergence of a consensus on the desirability of centralized electricity supply in Western Denmark.

The roots of the idea: The failed Jutland co-operation

The issue of joint exploitation of a large power station with participation by the municipalities, which had been discussed in vain in the years following the 1907 Electricity Supply Act, was taken up again in Jutland in the end of 1937.[29] On the initiative of plant manager Olaf Westergaard from Randers and mayor Mortensen from Esbjerg, all utilities in Eastern, Western and Mid-Jutland - production companies as well as transmission and distribution companies - were invited to discuss the possibility of a co-operation, including the common exploitation of a large power station. Several utilities protested to the idea, but representatives of others decided to finance a joint technical committee to further investigate the matter; participating utilities included the municipal utilities of Horsens, Vejle, Århus, Randers, Viborg and Esbjerg, the co-operative utilities from the Horsens and Kolding hinterlands, and the Gudenaa partnership. The technical committee also drew the Southern Jutland utility into the project, as the latter was eager to sell the surplus capacity of its large power station in Åbenrå, and therefore 'could not reasonably be excluded.' The study resulted in a scheme, where Southern, Eastern, Western and Mid Jutland should be supplied from the existing power stations in Århus, Esbjerg and Åbenrå and a new, jointly owned power station situated near Vejle or Fredericia, which would be the electrical centre of gravity in the system. The scheme promised a rather low electricity price (3.5 øre/kWh), provided that the participating utilities reduced their decentral production to at most seventy-five percent of the 1936-37 level and purchased the rest.

The plan failed, however, as particularly the Århus municipality opposed the idea of a joint power station. According to this large utility, the necessary production capacity could be obtained much cheaper simply by expanding the Århus power station. By 1939 the involved parties decided to drop the idea of common power station, and limit their co-operation to an investigation of the construction of a Jutland power grid.[30] Yet also this failed - it was at this occasion, that mayor of Horsens stated his famous words that he 'did not want current from Århus, even if it was totally free'[31] - until the Second World War forced the actors to comply with the interconnection project, but for the completely different reason of instant fuel shortages.

A concrete model: The South-Eastern Jutland co-operation

Already during the beginning of the negotiations on a Jutland joint power station, the four municipalities of Kolding, Fredericia, Vejle and Horsens - which commonly owned the partnership South-Eastern Jutland Interconnection - had taken up the issue of a joint power station. Yet as mentioned in chapter seven, in the late 1930s the partners still preferred a model of decentral expansion to meet the increasing electricity demand. The supply costs in both the schemes of decentral expansion and of a joint large power station would be cheaper for the four municipalities than purchase from the large utilities based in Århus and Åbenrå.[32] And a more detailed study on the feasibility of a joint power station had not shown very large economic gains. The study included a power station with a capacity of about twenty megawatts (equalling the capacities of the four decentral power plants) at a price of some five million krones, which should be situated in Vejle or Fredericia, and which should co-operate with the large Århus and Åbenrå power stations in order to save on back-up machinery. After some seven or eight years of operation, the annual savings relative to the scheme of decentral production would amount to some fifty thousand DKK, provided that the electricity demand had doubled. However, the indirect advantages of decentral production might outweigh this advantage: Reduction in local employment at the power stations, lost harbour incomes and lost incomes of other trades would reduce the citizen incomes by some hundred-fifty thousand DKK. The municipal councils therefore insisted on the decentral expansion scheme.[33]

When diesel fuel became scarce in the beginning of the Second World War, and the steam power capacity of the four municipal power stations was insufficient to meet the load, however, the four municipalities quickly agreed to interconnect to the steam power stations of Århus and Åbenrå to purchase additional electricity. Yet this situation also brought the issue of the joint power station back on the agenda. As the chairman of the South-Eastern Jutland Interconnection partnership, member of Parliament M. Larsen, complained in 1940, for the high costs of interconnection (some 800.000 DKK) the partnership could have invested in four diesel engines to double the capacity of the municipal power stations. But since diesel oil was scarce and interconnection a matter of fact, the partnership should find a strategy to avoid that the town power stations were reduced to mere transformer stations in a centralized system: Thus, he suggested to seriously think of implementing the joint power production scheme, which would be much cheaper for the municipalities than a purchase scheme.[34]

The year after, the joint committee of the four municipal councils univocally decided to build a common large power station with a capacity of some thirty megawatts, and at estimated costs of ten million krones. The wartime shortages of materials and increased construction costs (to some twenty-four million krones) caused the committee to postpone the project, but it was soon again taken up again with the argument that the active production units - Kolding, Vejle and Horsens still operated their steam turbine while their diesel engines were idle - wore out fast due to the constant overload.[35] As a favourable site, the village of Skærbæk at the Kolding Fjord was chosen. Moreover, to decrease the investments by the town municipalities, a request by the rural district utilities of the area to join in a common production partnership was accepted, and also the utility supplying the nearby town of Odder was invited to participate. The Odder utility refused, however, and would not participate until the mid 1950s.

In 1945, then, the four municipalities and the rural district utilities of the Horsens, Kolding and Vejle hinterland as well as the Mid-Jutland utility MES founded the partnership of the 'South-Eastern Jutland common power station' [*I/S den sydøst-jydske fællescentral, Skærbækværket*], in short the Skærbækværket partnership, after the location of the planned power station.[36] The partnership took over the sixty kilovolts interconnection operated by the partnership it succeeded, and constructed a new power station in Skærbæk with a capacity of sixty-five megawatts. When the new power station was taken in regular operation in 1951, the town power plants ceased their decentral electricity production, and became transformer and conversion stations. Thereby the participating actors had finally joined the West-Danish centralized system, although some utilities maintained a very small decentral production of electricity on small hydropower plants or the Kolding CHP plant.

Emerging consensus on the joint ownership model

During and after the War, the idea of joint ownership as a means to realize centralized electricity supply was increasingly praised both in the circles of traditional propagators for centralisation and in municipal interest organisations. With regard to the former, although the 1946 report did not address the ownership issue, professor Henriksen indeed praised the model in his presentations of the report. This is remarkable, as Henriksen had been the chief of the co-operation department of the Electricity Council, which had rejected the joint power plant scheme of the South-Eastern Jutland towns in the late 1930s, and urged the municipalities to purchase electricity from the existing large utilities in Århus and Åbenrå instead. But now he called the Skærbæk partnership 'a magnificent association, completely in line with the spirit of co-operation.'[37]

With regard to spokesmen for municipal utilities, consulting engineer Stenild Hjort, whose P. A. Pedersen firm consulted most municipal utilities and had always participated in the electricity supply debate as a spokesman of municipal interests, was among the first to raise the issue of joint ownership as a general model for future electricity supply to meet the growing electricity demand in Jutland. Already in 1941 - five years before government committee report - Hjort had presented this point of view at the Electrotechnical Society: He expected a doubling of electricity demand during the 1940s, which demanded a large expansion of the available production capacity. If efficient modern technology was to be used, the expansion of existing capacity should be limited to modern steam power stations and small hydropower stations; but the bulk (about two-thirds) of the required capacity could be installed in new power stations, which replaced the existing diesel power stations and old steam power stations. To meet to the large capital requirements, he suggested to build these power stations as 'joint power stations, where the participants are guaranteed the cheapest possible electricity through an optimal exploitation of the power stations.'[38] These large power stations would be interconnected in an expanded 60 kV power grid.

Hjort's scheme is remarkable, as propagators of centralized supply regarded his consulting firm as a crucial actor stimulating decentral consolidation and expansion of municipally exploited systems in the 1910s, 1920s and 1930s. When Hjort presented the results of municipal efforts to concentrate production in large power stations to the Electrotechnical Society in 1949, editor Kay Emun Rager went as far as to call his address for a great event of historical significance, comparable to NESA director Angelo's plea for centralisation in 1917: As Hjort would not have proposed the idea of centralisation without back-up from the municipal utilities, it showed that the principle of centralisation finally had been accepted.[39]

Indeed, Hjort's talks illustrated an emerging consensus on the arguments that Angelo had introduced in 1917, and which different government committees had emphasised since then: In a centralized supply system, the costs of electricity supply per unit were reduced due to modern machinery, scale effects and co-operation on a grid, which outweighed extra investment costs in a power grid.[40] Yet Hjort also insisted that for the municipalities, possible losses of municipal business interests as well as local employment should be deducted from the gains; as a result, the choice between centralized and decentralized supply depended upon individual calculations within the single municipality.[41]

Finally and most important, in circles of municipal interest organisations the issue was taken up immediately after the war. Thus, invited by the association of market-towns to introduce a discussion on the electricity supply business and in particular on the 1946 government report, plant manager Olaf Westergaard critically pointed at the ownership issue as crucial for the realization of 'effective and fruitful centralisation.'[42] He found it a 'certain truth' that the owner of the means of production earned a good profit. Yet whereas this formerly applied to decentral municipal production systems, this advantage also applied to large power stations with joint municipal ownership, which 'are exploited on similar terms by all participants.' Westergaard pointed at the Skærbækværket partnership as the pioneer project in this respect, and maintained that together with other co-operation projects recently initiated in Western Jutland and on Bornholm, this 'is the very best and most effective propaganda for centralisation, better than many meetings and voluminous reports.' He also reminded that if the Southern Jutland and Århus utilities had followed this line of joint exploitation from the beginning, they would have met less opposition from other actors in the field: But these large utilities had chosen to act as 'merchants with ownership right of the factories', and had tried to sabotage the idea of common power production from its beginning in the late 1930s.

In the same line of argument, Westergaard also criticised the large companies in the East-Danish centralized supply system for maintaining their profits instead of offering co-ownership and equal supply terms to other utilities in the region. In Westergaards opinion, 'the Zealanders should learn from the Jutland movement - this is the way that leads to the goal, that is, to ensure access to the cheapest possible electricity to everyone.' As we shall see below, within a couple of years this attitude became the official point of view of the association of market-towns, which would actively engage in negotiations with the production companies on the East-Danish centralized system on inclusion of market-town municipalities in the ownership of the East-Danish power stations.

The construction of the West-Danish centralized system

The municipalities and the concentration of production

In the years immediately after the war, three new regional production partnerships were founded after the model of the Skærbækværket partnership. First, in Western Jutland the director of the Esbjerg-based utility Jens Møller raised the issue of the 'partnership West-Jutland joint power station' in 1944 to the partners on the Western Jutland interconnection, which had been established in the first years of the War to make Esbjerg steam power available to other utilities in Western Jutland. In 1946, these negotiations resulted in the foundation of the partnership 'Western Power' [*I/S*

Vestkraft] by the municipalities of Esbjerg and Herning and the rural transmission company of the Esbjerg hinterland. The purpose of the partnership was to supply the partners with available thermal and hydro power and temporarily buy additional energy from the Southern Jutland utility. Yet the partnership also planned to expand the nine megawatts Esbjerg power station, which it took over from the Esbjerg municipality, so as to make it the primary power station of the region. To this purpose, its capacity was rapidly tripled with an eighteen megawatts turbogenerator.

In a first instance, other utilities in the area chose not to join, but instead maintain decentral production and purchase additional electricity from the partnership. In the 1950s, however, they did joined the partnership in return for a entrance fee. As in the case of Struer, the municipality might find this option cheaper than possible electricity purchase from the partnership: On one hand the price of purchased electricity was increased by five (for a fifteen years contract) to fifteen (for a five years contract) percent, while partners received power at cost price. And on the other hand, in case of purchase the municipality would have to build a 60 kV connection to the grid. Yet if it joined the Vestkraft partnership, the latter would finance a ring connection. As a result, the municipality calculated that power could be obtained about two øre/kWh cheaper as a partner, while the municipality would also gain influence in the partnership board. Therefore it joined the partnership in 1950.[43]

Like the Struer municipality, those of Ringkøbing and Skjern also joined the partnership in 1950. Later the municipalities of the towns of Varde (1953), Lemvig (1954) and Holstebro (1958) as well as co-operative utilities in the smaller towns of Grindsted (1951) and Ikast (1953) joined in. After inclusion and thus supply from Vestkraft at cost price, these gradually decreased their decentral production - often in tact with the change from the direct current distribution networks to alternating current supply (see below). By 1960, these utilities maintained only a marginal production in few small hydropower plants (Esbjerg, Herning and Holstebro) and a CHP plant (Lemvig). Finally, new partners included the rural transmission companies of the Ringkøbing county (1950) and of the Holstebro hinterland (1957).[44]

Second, on Funen the issue of joint power production was raised by the Svendborg municipality in 1946, when it sought an alternative to a recent plan of the large Odense municipal utility to expand its supply area to the entire island from a new large municipal power station. The Svendborg municipality first contacted the urban utilities in Fåborg, Assens and Nyborg and the municipal-consumer partnership on Langeland for negotiations on a joint power station for their towns, but already the same year the negotiations were expanded to include all municipalities on Funen. These resulted after three years of negotiations, and assistance from external consultants such as Stenild Hjort and professor Henriksen, in the establishment of two partnerships. In 1949 the partnership 'Funen Interconnection' [*I/S Den Fynske*

Samleskinne] was formed to complete a 60 kV ring on Funen. And in 1950 the partnership 'Funen power station' [*I/S Fynsværket*] was formed to establish a common power station near Odense. When the new power station was operational in 1953, the former partnership transferred its sixty kilovolts grid to the latter. From then, the Fynsværket partnership supplied electricity directly to the transmission networks of its partners. These included the urban municipalities of Bogense and Nyborg, which previously exploited local systems, and those of Fåborg, Middelfart, Odense and Svendborg which previously exploited town-based district systems. In addition, it included the privately owned Assens utility, the partnerships of urban municipalities and rural consumers on Langeland (including the Rudkøbing municipality) and North-Eastern Funen (including the Kerteminde municipality). All producing partners agreed to cease their decentral electricity production, with the exception of a marginal production following the CHP production in Fåborg, Nyborg and Svendborg.[45] Finally, although rural utilities had not been included in the negotiations, the urban municipalities agreed that rural transmission companies could join the partnership.[46] This possibility was for instance used by the new Funen association of transformer societies in 1950 and the transmission company of the Svendborg hinterland, which had been founded in 1953 to take over the transmission grid from the Svendborg municipal utility.

And third, also the existing centralized system in Mid Jutland was reorganized. Negotiations on joint ownership were taken up in 1946. Like the Funen partnership, however, these required mediation from outside - in this case by Professor Henriksen and NESA director Angelo - before the participating utilities could agree upon a final contract on the establishment of a Mid Jutland partnership [*I/S Midtkraft*] in 1950. The partnership obliged itself to purchase the entire production of the hydropower station in Tange, and took over and expanded the large power station in Århus as a jointly owned primary power station. Moreover, in the mid 1950s the partnership also took over the existing sixty kilovolts interconnections and transmission lines from the Gudenaacentralen partnership, and would thus supply its partners at their respective transmission networks. The founding partners were the municipalities of Ebeltoft, Skanderborg, Grenå, Silkeborg, Skive, Vejlby-Riskov, Viborg, Åby and Århus and later Hobro (1951), most of which had operated decentral production systems, which were now closed down. In addition, the partnership included a number of rural utilities such as the rural transmission companies ARKE and EGO and small rural utilities of Braband, Bjerringbro, Hammel, Kjellerup and Viby and two small transmission companies. Also the producing utilities among these closed down their decentral production systems.[47]

Within a decade, the electricity supply structure in most of Western Denmark had been reorganized according to the model of concentration of production with decentral ownership.[48] Besides the four new partnerships, this included of course the Southern Jutland utility, which had been established in the early 1920s as a co-operative society of rural transmission companies and the single municipality of Åbenrå, where its large power station was situated. In the following decades, this co-operative society also adopted other municipalities of Tønder (1935), Haderslev (1935), Sønderborg (1938) and Ribe (1952), which thereafter ceased their decentral production apart from that of small hydropower stations.[49]

The Southern Jutland utility and the new partnerships functioned in a similar way; like the Southern Jutland utility, the new partnerships exploited the power stations as well as primary transmission networks, and the costs of exploitation were financed by the partners according to their share of the production. Normally, fixed costs were shared after their maximal load (the so-called kW fee), while variable costs were shared according to the amount of energy taken from the grid (the so-called kWh fee). These associations then supplied electricity at cost price to the distribution companies of the partners. The great advantage of this arrangement, as city treasurer Sørensen of the Mid Jutland town of Skive put it in 1953, the 'political issues'- particularly pricing policy - were maintained at the decentral level, and did not concern the co-operation.[50]

By 1954, then, these five jointly owned companies exploited a centralized electricity supply systems with power stations in Åbenrå, Skærbæk, Esbjerg, Århus and Odense, which could co-operate on an expanded sixty kilovolts power grid. At this time, the West-Danish centralized system only excluded the Northern and North-Western parts of Jutland (figure 9.3).

With regard to the Northern parts of Jutland, finally, the same model of jointly owned centralized supply would be implemented with a decade's delay. Early negotiations on the establishment of a Northern partnership [*I/S Nordkraft*], which would take over the power station of the Ålborg municipal supply company, had failed as the involved parties could not agree on the costs of expansion of the power station and resulting increases of electricity prices.[51] Later, another issue of disagreement was the use of the Ålborg power station to co-produce district heating; the other parties feared that its operation would be optimized after heat production in Ålborg, and electricity prices for the other municipalities thus would be higher than they needed to be. In the intermediary period, the actors involved found a different model of centralized supply. On one hand, the Ålborg municipal utility sought interconnection in the West-Danish grid in the mid 1950s, thereby becoming part of the centralized system as it joined with a its large power station. On the other hand, as described in chapter seven, in 1951 the municipalities of the Vendsyssel area (Brønderslev, Hjørring, Nørresundby, Skagen and later Frederikshavn) and also some rural transmission companies formed the partnership NEFO to purchase additional electricity from the Ålborg utility through an expanded sixty kilovolts grid. As the Ålborg utility already supplied the Northern Jutland area below the Limfjorden, it became indeed a primary power station supplying most of Northern Jutland, although it co-existed with the decentral power stations of the Vendsyssel municipalities. First in 1960 the Ålborg municipality and a rural transmission company formally formed the partnership Nordkraft to supply the Northern Jutland area below the Limfjorden, while the NEFO partnership decided to build its own large power station after the joint ownership model without participation from the Ålborg municipality. The latter's power station was operational in 1967.

Coordination of the system and a new 150 kV power grid

During the 1950s, the West-Danish centralised electricity supply system was further developed. Not only did it absorb the Northern parts of Jutland, but the large production companies in the area also build a new power grid of higher capacity, and formed formal organisational ties for the administration and coordination of the system. The latter innovations were related, in that the ever increasing capacity of the production units in the different primary power stations gave cause to a problematisation of the security of supply. This concerned both the loose, voluntary organisational structure of coordination of energy exchange on the grid, as well as the transport capacity of the sixty kilovolts grid, which was insufficient to transport capacities in this order of magnitude; the latter problem became particularly pressing when sixty and eight megawatt units were introduced in the 1950s, while the transmission capacity of the 60 kV grid was typically at some thirty or forty megawatts MW, and thus insufficient to replace a failing production unit.

With regard to the power grid, a study on the feasibility of a grid of higher capacity had already been conducted by the Vestkraft partnership in the second half of the 1940s.[52] Its report stressed that the lack of production capacity after the War caused frequent overloads of the production machinery (resulting in reduction of the frequency) or even black-outs. Thus there was a need for back-up units. According to the report, it was economically attractive to obtain this back-up through co-operation, even though this required a new power grid of higher capacity. The savings on investment in backup capacity by about a third would outweigh the construction costs of the grid, resulting in a total saving of some eighty-one million krones. Moreover, an increased co-operation would save about five percent on annual running costs through load management, amounting to a reduction in annual expenses of eight million krones by 1955.[53]

The report thus repeated the arguments for centralized supply known since the First World War. In addition, it presented a concrete design of a new high capacity power grid, able to transport the necessary amounts of energy. The design was presented to the 'Committee for steam power stations in Jutland and on Funen', the loose body of representatives of different utilities which coordinated and administrated the power exchange on the existing 60 kV grid. The committee appointed a technical subcommittee, consisting of representatives for the five large production partnerships, supplemented by professor Henriksen as an external consultant; this sub committee then agreed upon the form and operation voltage of the grid of 150 kV.[54]

Once this agreement was reached, as director Jes Christiansen of the Southern Jutland utility put it, 'the next issue is to reach agreement on the organisational arrangement.'[55] The problem of the existing arrangement was that the loose organisational structure of the centralized system could not guarantee that the partners provided mutual back-up capacity, nor that they adapted operation to optimize the overall economy of the system; the 'Committee for steam power stations in Jutland and on Funen' did not have formal competences, and the system was regulated by a consensus on the expansion of production capacity and a number of contracts between individual production companies on energy exchange.

The negotiations on a new arrangement continued during most of the 1950s. While there was agreement on the necessity of a central coordinating body with increased authority to direct supply in case of break-downs, there was disagreement between the actors on the competence of such a central body in normal supply situations. On one hand, this concerned the co-operation to optimize the economic performance of the system through load management. A committee appointed to study the issue of economical co-operation in 1953 found the model of joint exploitation of the power stations, as practised by IFV and SEAS in Eastern Denmark, unsuitable: For contrary to IFV and SEAS, most West-Danish actors operated CHP plants with a responsibility for local town heating. In addition, while IFV and SEAS trusted that both worked to optimize the common economy, the West-Danish actors lacked such confidence in each other; solidarity had been achieved within the different production partnerships, not between them.[56]

Instead, the committee recommended a model of an electricity auction as practised in the United States. In this model, the individual production companies would retain full independence with regard to operation of their power station. To facilitate economic advantages through energy exchange, the companies would offer additional electricity for a certain load at certain prices to a neutral 'load manager', who would make operation schemes of the power stations involved to achieve the optimal economy of operation. Organisationally, this coordination should be accommodated within a new partnership of the production companies in the centralized system, which should function as operator of the grid, arranger of emergency supply, neutral load manager, and in the future also arrange imports from Norway and possibly build and operate a common nuclear power station.[57]

The final organisational model was imported ready-made from the Netherlands, where the largest production companies had established a national partnership in 1949, which answered to the concerns of the West-Danish production companies: In the Dutch agreement, the individual production companies fully owned and controlled their power stations except in emergency situations, in which case the central partnership had the competence to arrange their production and energy exchange. The central partnership also developed supply schemes to achieve an optimal economy of supply, but these had a voluntary status. With regard to the construction of a national power grid, it were the partners who constructed and maintained those parts of the grid in their own supply areas.[58] The West-Danish actors on the centralized system - the Southern Jutland utility, the four production partnerships and the municipal utility of Ålborg - adjusted the Dutch agreement to their situation, and founded the central partnership ELSAM in 1957. All partners were represented in the executive board as well as the technical department of the new partnership; moreover, they retained almost full independence as owners and operators of the means of production, maintaining the right and duty to supply the base load to their own supply areas. Yet the central partnership had compelling authority with regard to emergency deliveries between the parties, and also in principal obliged the actors to maintain sufficient production capacity including back-up to supply their own areas - although there was room for dispensation. Finally, the partnership made running and exchange schemes to optimize the economy of supply on a voluntary basis only, had the authority to deal with imports and exports of electricity and might in the future exploit a nuclear power plant.[59]

With regard to the concrete construction of the new power grid, the partners agreed to build a scheme, which largely following that of the 1949 report. It consisted of interconnections, transmission lines and supportive lines (figure 9.4): Interconnections were to facilitate energy exchange between the power stations, and should be used for transmission purposes only if it did not disturb energy transport for co-operation. These interconnections followed the shape of the so-called 'co-operation cross', including a North-South interconnection from Ålborg via Århus and Skærbæk to Åbenrå, and an East-West interconnection from Odense via Skærbæk to Esbjerg. This design was preferred to a 'ring design', as it only demanded 380 km of interconnecting lines, and thereby could be established fast and cheaply. These interconnections should be built by each participant in its own supply area. Transmission lines were only used by the individual production companies to distribute the electricity and were to be built by them, while in a later stage supportive lines between the partners were to be jointly in order to increase the security of supply. For all lines and stations, the ELSAM partnership set technological minimum standards.[60]

By 1960, the West-Danish centralized supply system consisted of 150 kV and 60 kV power grids interconnecting eight large power stations; besides the five power stations of the mid 1950s, the Ålborg power station, a second power station in Southern Jutland (1958) and the CHP plant in Randers had been included.[61]

Municipal participation in the East-Danish centralized system

The inclusion of municipalities in the centralized system

The innovation of jointly owned centralized supply also appealed to the East-Danish municipalities: For instance, by the late 1940s chairman A. K. Jørgensen of the electricity committee of the Holbæk municipality on Zealand argued that the electricity purchases from the centralized system following the Second World War had perhaps come to stay; yet to accept this scheme as a permanent arrangement, the municipalities demanded co-ownership of the means of production. Moreover, director H. Buhl of SEAS could reveal that his company was currently negotiating with the utilities on Lolland-Falster on an arrangement of joint ownership.[62]

In 1949, also the association of municipal utilities decided to work for municipal co-ownership of the power stations in the East-Danish centralised system. In his introduction to the discussion, Hans Bagge provided two main arguments. First, the model in which the urban municipalities on Zealand, Lolland and Falster merely purchased additional electricity from the large power companies was dissatisfactory in the long run, as the respective contracts with NESA, NVE and SEAS did not guarantee the municipalities the cheapest possible electricity prices. Moreover, he found it unreasonable that the municipalities paid substantial amounts of money to these utilities, but did not have any influence on their policy. In view of the situation in Western Denmark, where 'supposedly ... all West-Danish utilities would be joint owners of large power stations', the executive committee of the association found that it should work for a similar arrangement for Eastern Denmark. For Bagge, this meant ownership of all large power stations; he was not satisfied with an idea proposed by consulting engineer Hjort to establish a single joint power station near the Great Belt. According to Bagge, the costs of participation in the large power stations would be lower than the costs of decentral production and expansion, while the municipal utilities would gain influence on such matters as operation, tariffs, supply conditions, the timing of expansion etc. The large companies, he argued, should be susceptible to the municipal demand: They not only knew that the satisfaction of the West-Danish municipalities would inevitably raise a similar demand in Eastern Denmark, but also needed the extra capital these actors could provide for expansions, which soon would be necessary.[63]

Second, Bagge argued, municipal participation in the centralized system would also solve difficulties concerning the current negotiations on the property rights on imported hydropower. Not only would NESA's concession on import of Swedish hydropower run out in 1954. There were also negotiations at the government level on the import of hydropower from Norway, which was expected to be even cheaper than the Swedish hydropower.[64] The production capacity was not yet available in Norway, however, and the plans would take at least a decade to be realized. Still, it inspired the municipalities on Zealand to appeal to the association to work for their inclusion in current negotiations. The association of municipal utilities then managed to get a representative in the government committee to work for equal rights to hydropower imports for the municipalities. The problem remained, however, that the large supply companies NESA, NVE and SEAS owned the transmission grid, which would transport this hydropower to the municipalities. If the municipalities were to become joint owners of the large power stations as well as the grid, this problem would be eliminated, and the municipalities would no longer be an outsider in the negotiations.[65]

The association of municipal utilities then univocally accepted a resolution demanding co-ownership of the East-Danish centralized system. To realize this goal, a large majority decided to form a committee with representatives from the association as well as the regional associations of municipalities in the NVE, NESA and SEAS supply areas on Zealand and on Lolland-Falster to negotiate with the large companies on co-ownership of the large power stations.[66] With Bagge as its chairman and Hjort as its technical consultant, the committee achieved part of its task by 1953: After four years and some thirty meetings, the owners of the largest production company, the IFV partnership, agreed to include the municipalities in the NVE and NESA distribution areas in the partnership. Hence the municipalities of Frederikssund, Frederiksværk, Helsingør, Hillerød and Roskilde, which all still exploited local systems, joined the partnership along with NESA. In addition the municipalities of Holbæk and Sorø exploiting local systems, those of Kalundborg and Slagelse exploiting district systems, and that of Nykøbing on Zealand, which had not exploited a production company, joined along with NVE. The towns should participate with capital relative to their electricity demand, which they raised through a common loan of thirteen million krones at the loaning association of market-towns.[67]

Hereafter the municipal utilities became primarily distribution companies, which bought their electricity from the production company at the nearest 50 kV transformer station at cost price - plus a fee for using the transmission grids, which were still owned by NESA and NVE. The agreement made decentral production unattractive; decentrally produced electricity was to be sold to IFV at the low IFV prices. Unless this concerned CHP production, this would be an expansive affair for the municipality.[68] By 1960, only few municipal power stations were maintained, but these did not have any significant production. The Holbæk power station, for instance, operated for eleven hours only in 1960; thereby it does not qualify as an independent decentral system in the definition in this dissertation, but only as a peak power station in the centralized system.[69]

The negotiations with SEAS on the inclusion of municipal utilities in its supply area, by contrast, failed. Yet the negotiations did result in satisfactory purchase agreements, which made the municipalities opt for inclusion in the centralized system as purchasers. On one hand, several urban municipalities on Southern Zealand (Korsør, Køge, Næstved, Ringsted and Vordingborg) joined in an association of electricity purchasers from SEAS in 1954. Through this association they also participated in the hydropower imports. The utilities of Nakskov, Maribo, Rødby, Nysted and Sakskøbing on Lolland, co-operating in a partnership, were supplied in a similar way from 1957, when SEAS purchased the transmission network of the Lolland partnership. On the other hand, other municipal utilities were simply purchased by SEAS, including the Zealand municipal utilities of Skælskør (1949), Stege (1949) and Fakse (1957). As SEAS was a consumer owned limited company, and partly paid for these utilities with shares in the company, these municipalities indeed became owners in the company.[70] As a consequence of these strategies, by 1960 also decentral municipal production on Southern Zealand and on Lolland-Falster had virtually ceased.

Technical expansion of the system

By 1960, the East-Danish centralized system had been further expanded. With regard to the thermal production capacity, the IFV partnership had decided to build a second power station, when its power station at the Isefjord was fully expanded (to 270 MW) by the mid 1950s: The new power station was situated at the Kalundborg Fjord at the Western end of the system, and its first 120 MW turbine was inaugurated in 1959. This was then the largest single production unit in Denmark.[71] The SEAS production company managed its supply with one power station until the mid 1960s, when it likewise inaugurated a new power station. The municipal supply company of Copenhagen, finally, did not inaugurate its third power station until the early 1970s.

In addition, the capacity of the interconnection with Sweden was considerably increased. When NESA's forty years concession on the exploitation of the connection to Sweden expired in 1954, the organisational setup was indeed changed to include all municipalities in the supply area of the East-Danish centralized system.[72] Thus the three large production companies, now including all Northern Zealand municipalities, jointly with the associations of municipal utilities on Southern Zealand and on

Lolland/Falster founded the 'power import' partnership [*KRAFTIMPORT*] to exploit the connection and supply its partners with imported hydropower. Administration and coordination of the KRAFTIMPORT partnership were again delegated to the IFV partnership, and physically situated at the NESA control centre Ørnegaarden (from 1959 transferred to the new control centre 'Glentegaarden').[73] The KRAFTIMPORT partnership signed an agreement on energy exchange with the new Swedish partners, the co-operating production companies of Sydkraft and the Kgl. Vattenfallsstyrelsen. Already in 1954 the Danish partnership financed two additional high capacity cables, operated at one hundred and twenty kilovolts, to increase the import capacity. But the since the late 1920s, thermal power had also incidentally been exported to Sweden in times of drought and the subsequent shortages of hydropower. Following a major drought and the lack of fuel due to the Suez crisis, the Swedish partners imported a particular large amount of power from Eastern Denmark in the winter of 1956/57. Hereafter, the Swedish partners decided to finance a third 120 kV cable. The transport capacity of he submarine interconnection was thereby increased to 165 MW. In the first half of the 1960s, the transport capacity was again increased to 360 MW.[74]

Finally, like in Western Denmark the East-Danish actors built a new power grid of still higher capacity. The necessity of a larger transport capacity had been identified by the IFV and SEAS companies in the late 1940s, when they feared a shortage of transmission capacity in case of emergencies. It was then suggested to expand this capacity 'as quickly as possible', possibly with 120 kV lines. Each company should build the trajectory in its own supply area.[75] However, NESA's calculations on a new grid computer, which could simulate the effects of a short circuit, load distribution and stability on the grid, showed that the capacity of the 50 kV grid was still sufficient, and the construction of these very expensive 120 kV lines could be postponed for 'a number of years.'[76] And although for instance SEAS built the trajectory from its Masnedø power station to its central junction of Haslev in the late 1940s, the line was for the time being operated at 50 kV.[77]

The issue was again put on the agenda with the establishment of KRAFT-IMPORT, where the SEAS and Copenhagen utilities argued that the imported hydropower should be delivered directly to their power stations. The IFV partnership opposed to this arrangement, however, and it was again agreed that each partner should built its own stretch of the grid.[78]

By 1960, then, the East-Danish centralized system included five very large power station, a new 120 kV power grid besides the old 50 kV power grid (figure 9.5). The three production companies supplied virtually all electricity to Eastern Denmark: In terms of energy consumption, the IFV/SEAS co-operation covered about 63% of the area: SEAS supplied 16% of the energy, NESA 35%, Frederiksberg 5% and NVE

7%. The Copenhagen utility supplied the remaining 37%.[79]

The issue of alternating current supply

As a result of the choices of the Danish municipalities, then, the huge increase in demand in the post war period coincided with the increasing success of centralized electricity supply. Notably, this huge increase in electricity consumption in itself posed increasing supply problems, particular with regard to the capacity of the low voltage, direct current distribution networks of both municipally exploited local systems and town-based district systems, as the latter normally had direct current distribution for the town area. In addition, consumers increasingly preferred alternating current supply for their appliances.

As described in the next chapter, these developments would prove important for the abandoning of small rural local systems. Yet for municipal utilities, they were not decisive in the same degree. This is not because they weren't major concerns for municipal utilities: Indeed, the issue was taken up by the association of plant managers in a 1948 report, which argued that transition to full alternating current supply was unavoidable from a technical point of view. The rapid increase in consumption as well as the increasing range of appliances designed for alternating current simply outdated direct current supply.[80]

Yet, it is important to note that the municipalities did not necessarily link this issue to the issue of decentral vs. centralized supply, as many rural utilities did. On one hand, often the municipal decision to join the centralized supply scheme preceded the problematisation of direct current supply, which particularly occurred from the late 1940s. And on the other hand, the decentral production of alternating current was a nearby option. In fact about all municipal utilities with a larger supply area, that is, some thirty town-based district systems, already produced alternating current decentrally, and alternating current transmission and distribution could relatively easily be expanded to the inner city. The decision for centralized supply, then, primarily followed the attraction of the model of decentral ownership of the centralized supply system.

Some examples may illustrate this point. First, an example where the decision for centralization preceded the post war supply problems is the Vejle municipality. When the Vejle municipal council accepted the South-Eastern Jutland common power station scheme in 1944, the size of decentral alternating current production primarily to industry and rural consumers had already exceeded that of direct current production for inner city residents. Only half a decade later, in 1949, the inner city distribution system was problematised: After a break down under the peak load of

Christmas lighting, the municipal council agreed to change also the inner city system for alternating current supply. Between 1950 and 1956 supply to the town area was rebuild, from a 440 volts direct current system to a six kilovolts alternating current system supplying several transformer stations, which in turn supplied the consumers with alternating current at 220/380 volts.[81]

Second, two later examples of Holbæk and Slagelse in Eastern Denmark illustrate that even though the decision for centralization more or less coincided with increased supply problems, the latter were not necessarily decisive. In Holbæk, where the municipality exploited a local system and since the Second World War also purchased additional electricity from the NVE company, in 1947 the electricity committee of the municipal council foresaw increased supply problems in the next decade.[82] To anticipate the expected doubling of the electricity consumption, it would be necessary to increase the supply capacity as well as to upgrade the distribution network. It realized that by 1960 the 440 volts distribution network would not be able to carry demand; in addition, consumer preferences for alternating current supply became increasingly important, and the local business association urged the committee to speed up the transition to alternating current supply. The committee therefore recommended a transition to alternating current supply with transmission at ten kilovolts to about ten transformer stations in the outer districts of the town within a decade or two. The situation became even more pressing, when the electricity demand increased faster than expected (demand tripled instead of doubled).

However, contrary to the rural utilities studied in the next chapter, the municipality did not relate this issue directly to a transition from decentral production to purchase of electricity, and the 1947 report of the electricity committee recommended - besides a change to alternating current supply - to adapt the local power station for alternating current production. The municipal council accepted this proposition. If the decentral expansion was not carried out in practice, this was primarily the result of the newly started negotiations with NVE on participation in the IFV production partnership. For the Holbæk utility, it was not in the least the issue of hydropower imports that motivated participation in the negotiations, besides the important issue of receiving thermal electricity at cost price.

In Slagelse, by contrast, the municipality had already run a town-based district system with alternating current supply to the hinterland from the late 1910s.[83] Moreover, already since the mid 1930s the utility had started a transition to alternating current supply to the outer districts of the town itself as well as industrial enterprises desiring alternating current supply. Thereby it anticipated future distribution problems and clashes with consumer groups demanding alternating current supply. When expansion of the supply capacity was demanded in the late

1940s, the municipality decided a modest decentral expansion with a new CHP unit, which was realized in 1950 as described in chapter seven.

Still, also the Slagelse municipality was interested in negotiations with NVE. In this case the interest followed a desire for lower prices for its significant purchases of additional electricity. For although its decentral production was doubled between 1946 and 1950, the rapid increase in demand caused equally large increases in additional electricity purchase. Also in the case of Slagelse the results of the negotiations were decisive, and when the municipality joined the IFV partnership in 1953, it decreased its decentral production with a factor 20 to merely follow the heat production in the CHP units.

In the 1950s and 1960s, then, the role of municipalities as decentral producers of electricity was greatly reduced, while at the same time municipal production companies were reorganized as municipal transmission and distribution companies (table 9.1). In 1950, there were still seventy-three municipal utilities with decentral production systems. The large majority of these operated decentral local or district systems in Danish provincial towns, while five exploited local village systems and a few (Copenhagen, Odense and Esbjerg) produced on a centralized system. By 1960, their number had decreased to merely twenty-six, and by 1970 only eight remained.

Table 9.1: Producing and non-producing municipal utilities in Denmark 1931-1970.[84]

	Municipal production companies	Municipal transmission & distribution companies	Total of municipal companies
1931	78	10	88
1939	71	11	82
1950	73	13	86
1960	26	44	80
1970	8	57	65

This final municipal choice for centralized supply was not merely an acceptance of the 'most rational' electricity supply form in the ahistorical and context-independent sense, as it had been advocated by propagators of centralization since the 1910s. This is particular illustrated by the developments in Western Denmark, where at least two crucial events involving the context of electricity supply completely altered the technical-economical comparison between the different electricity supply options, and made municipal participation in centralized supply attractive. First, the historically contingent factor of fuel shortages of the Second World War had caused the municipalities to agree with interconnection and resulted in the establishment of the first West-Danish power grid. Although the middle-sized and smaller municipalities complied with this project in a spirit of 'decentral co-operation', it also changed the economic feasibility of centralized supply relative to a decentral supply structure, since the investment in an expensive power grid already had been made.

And second, the municipal acceptance and participation in the physical construction of a centralized supply system in Western Denmark was interrelated with the social innovation of co-ownership of the means of production, which combined the traditional economic advantages of large scale supply with the advantages of decentral municipal ownership and control. Only in Southern Zealand and on Lolland and Falster this innovation failed, and here the municipalities were enrolled in the centralized supply system after a process of negotiation on the terms of electricity supply with the large utility of the area. Also this closure mechanism proved successful, and will be further examined in the next chapter for the case of rural utilities.

10
The decline of rural systems

During the 1950s and 1960s, also decentral rural electricity production systems in Denmark massively disappeared, and by 1970 remained only a few systems, which mostly exploited cheap hydropower units or were situated on small islands. This abandonment of decentral systems by the actor group of consumer associations is often interpreted as their final acceptance of the technical and economical superiority of centralized supply. However, as demonstrated in chapter eight, the economical and technical performance of rural systems were not a matter of fact, but rather a matter of interpretation; indeed, consumer associations had massively consolidated their decentral rural systems with reference to their technical and economical feasibility at least until the 1950s, when there had still been more than two hundred of such systems. The radical change in their choice of supply system thus requires a more detailed examination of the mechanisms involved.

To develop a grip on the large amount of rural utilities, this chapter investigates the choice of supply option by consumer associations both at the level of interest organisations and for selected cases. Again, the focus is upon the large majority of rural utilities exploiting a local system; the few utilities, which exploited a district system, were normally large enough to become partners in the centralized system on similar terms as municipal utilities and rural transmission companies, and thus adhered to the closure mechanism described in the previous chapter.

Consolidation and centralisation in the discourse of decentral rural supply

During the 1930s, representatives of small rural utilities had had little doubt on the economical and technical feasibility of rural local systems. Economically, the low costs of large scale electricity production were not felt by the consumer at the end of the transmission and distribution network. And technically, the only advantage of alternating current systems was the possibility to transport electricity economically over large distances, but this was rather irrelevant for rural local systems with their small supply areas. In fact, local systems were regarded technologically superior thanks to their high reliability of supply compared to large scale supply systems using high voltage transmission.

After the Second World War, however, this view became more nuances, also in the discussions in the interest organisations of the rural utilities. The assessment of the economic and technical performance of the different supply options remained often to the advantage of decentral production; yet, it was increasingly recognized that the economic competitiveness of centralized supply was rapidly improving. In addition, despite the continued superior reliability of local electricity supply, the criteria of technical feasibility were gradually reformulated as the rapid increase in demand exceeded the capacities of low voltage distribution networks. And finally, a new element was the increasing consumer demand for alternating current supply. While these concerns played a smaller role for municipal systems using direct current distribution, they made spokesmen of rural utilities increasingly pessimistic on the consolidation of local village systems. This is illustrated by the last vers of a song, sung at the annual meeting of the Jutland association of rural utilities in 1951: 'Direct current utility, when time is in/ and it probably won't take long/both you and we shall disappear/return to dust and rusty scrap' [*Jævnstrømsværk, når tiden er inde/ og den er vel ikke mere fjern/ da skal både du og vi forsvinde/ blive støv og gammel rustent jern*].[1]

Ownership and the economic competitiveness of centralized electricity supply

First, then, representatives of rural utilities increasingly pointed at the new situation of jointly-owned production partnerships as a new important precondition for electricity purchase. As chairman of the Jutland association of rural utilities Vilhelm Mondrup recognized in his annual address already a few months after the Liberation, even in Jutland the competition between centralized and decentralized supply systems on supply prices would become tough. On one hand this followed from technical improvements: Unlike most older large power stations in Jutland, the new very large steam power plants that were under construction would use modern equipment, and would achieve significantly lower running expenses. And on the other hand, the innovation in ownership was at least as important: While previously almost all large power stations had been owned by municipalities, which operated them with a profit for the municipal treasury, the new large power stations planned in Jutland were organized according to co-operative principles. The production partnerships would not charge a profit, but supply electricity at cost price to their member distribution companies. As a result, Mondrup expected that rural utilities would be offered electricity at much more attractive prices than previously. Although he did not doubt that larger local systems with a small and concentrated supply area would remain competitive, it would be increasingly difficult for smaller systems to compete.[2] Yet, it would probably take a decade before cheap and reliable electricity was available from the new centralised system: For the time being, the centralised system with its uneconomic, worn out machinery and high solid fuel prices was not competitive.[3]

Similar arguments arose at the joint meeting of all regional associations of rural utilities in 1949.[4] Here, director of the large Southern Jutland utility, Jes Christiansen, had been invited to speak on large scale supply. The audience, as the chairman of the Funen association put it, 'hoped to shoot down the arguments' of this traditional adversary. But instead it was impressed by the low prices offered in Southern Jutland - prices which certainly did not match those elsewhere on Funen and Jutland. This was attributed to the organisational form: Christiansen was recognized as 'a man of co-operatives' with concerns similar to those of the small consumer associations. Even the polemic and sceptical C. E. Jensen regarded Christiansen as 'a sympathetical high voltage man'. Thus, the problem might not so much be the supply form of centralized electricity supply itself, but rather the influence of municipal directors and mayors on the electricity supply business. The chairman of the Funen association emphasised that it was the enrollment of rural inhabitants as indirect tax payers to a town municipality, that had made electricity supply from the large power station in Odense to rural utilities on Funen so expensive, despite the fact that the Odense municipal company purchased part of its power directly from the cheap Southern Jutland utility. The organisational structure of the new partnership Fynsværket according to the principles of joint ownership might change the situation to the advantage of centralized supply. A similar view was expressed by the plant manager of the Åbyhøj utility near Århus: It was a price level like that of Southern Jutland, that the Mid-Jutland utilities sought to achieve by jointly taking over the power station of the municipal utility of Århus through the establishment of the Midtkraft partnership.

During the 1950s, then, the technical and organisational construction of centralised supply rapidly restructured the supply situation also in the countryside in Western Denmark. While the purchase option for small rural utilities previously often implied supply from a municipality utility, either directly or indirectly via a transmission company, it now increasingly implied purchase directly from a transmission company, which received its power at cost price. By 1960, nearly thirty rural transmission companies had joined a production partnership, either directly or indirectly through co-ownership of another transmission or production company. Besides the large NVE and NESA companies in Eastern Denmark, these were all situated in Western Denmark. Only rarely such transmission companies continued to purchase electricity from a municipality: Of the eleven companies that did so, most were situated in the Vendsyssel area in Northern Jutland, where a production partnership had not yet been established. When such a partnership was established in the early 1960s, also these transmission companies became co-owners.[5]

In addition to this development, consumers or transformer societies previously supplied by a municipal utility might establish new independent transmission companies in order to join such production partnerships directly. As a result, the share of the municipal utilities in rural supply further decreased. An example is the transmission company for rural Funen [*Elforsyningsselskabet For Fynske Landdistrikter*, EFFLA], which was founded in 1950 by transformer societies in the supply area of the Odense municipal utility. The company purchased part of the ten kilovolts transmission network from the Odense municipality, and then joined the partnership Fynsværket as an independent partner. Another example concerns the hinterland of Randers; in 1954 the consumers (land owners) in the area founded the ELRO [*Elforsyningen for Randers Opland*] transmission company, which purchased the large rural transmission network from the Randers municipal utility. Electricity was still purchased from Randers, until the company became an independent partner in the Midtkraft partnership in 1959, whereafter it received power from the centralized system at cost price.[6]

In view of these developments, by 1953 Vilhelm Mondrup had become a supporter of the ongoing development of concentration of production. He found the co-operative organisation of the centralized system decisive in this respect, repeating the argument heard in municipal utilities and their organisations in the previous decade that 'it seems irrelevant if we produce our own electricity, or receive it from large co-operative societies, of which we are the owners.' He maintained that the 'soundest' development included centralized production combined with decentral distribution by independent distribution companies. In this way, consumers themselves kept full control with their tariff policy.[7] Also for rural utility organisations, then, the economy of centralized supply was closely linked with the organisational innovation of joint ownership.

The technological feasibility of local systems

A second change in the assessment of the different supply options concerned their technical feasibility. This is not to say that local village systems lost their general advantage of reliability: Even though it was recognized that large utilities had succeeded to reduce the number and duration of power cuts, partly by improved transmission grid designs and partly by improvements of the most vulnerable system components, still in 1960 there was agreement that reliability remained the Achilles' heel of large scale supply. But following the huge increase of electricity demand also on the countryside, local systems had increasing difficulties in suppling electricity in sufficient quantities and of sufficient quality (i.e. of a steady voltage) to their consumers.

The problem had already been identified by Mondrup in the second half of the 1940s: The ever increasing electricity demand not only put a strain on the production capacity of local systems, but also on the capacity of their low voltage, direct current distribution networks. This was not only so for utilities supplying relatively distant consumers over long transport lines, but also for utilities in small station towns, where 'each apartment in time would obtain its own kitchen'. For instance, in his annual address to the Jutland association of rural utilities in 1947, he quoted the executive board of a rural utility for assuming that centralized supply was the supply form of the future, '... regardless how cheap direct current can be supplied, simply because local systems can't cope with supply of the large consumption technically.' At the expense of being accused of 'agitation' for alternating current supply, Mondrup completely agreed to this judgement.[8] Few years later, also chairman Rs. Petersen of the Lolland/Falster association of rural utilities stated that alternating current supply would be necessary in the long run to satisfy consumers on larger distances.[9] The technical feasibility of local systems had been reformulated from an advantage in reliability to a disadvantage in quality and quantity of supply.

To investigate the issue more closely, the Jutland association of rural utilities invited consulting engineer Aage Brix-Pedersen to address the association in 1949.[10] Also Brix-Pedersen recognized that the rapid increase in electricity consumption would put increasing demands on the capacity of local systems. And while production capacity could easily be increased with a new diesel engine or additional purchase through a converter, the problem of distribution capacity remained. The problem, he reminded, was not new. Many rural utilities had earlier experienced that the often used 110 volts distribution systems became difficult to maintain and expand. Most such systems had either been abandoned, or been changed to a 220 or 440 volts system. In the post war period, however, the increasing electricity consumption would also make economic distribution in 220 or 440 volt systems increasingly difficult. Therefore Brix-Pedersen urged rural utilities not to expand their supply area beyond the economical supply distance of roughly one kilometre for 220 volts systems and three kilometres for 440 volts systems. In such cases, local systems would remain economically and technically feasible.

Unfortunately, many rural utilities in fact had already exceeded these distances, and currently faced technical and economical problems as voltage drops, increased power losses due to large currents, or high expenses following the installation of thicker wires. To solve these problems, Brix-Pedersen recommended a gradual change from direct current to alternating current distribution, which eventually would have to be introduced; upgrading for instance a 220 volts system to a 440 volts system would be a rather expensive way to merely postpone the problem. Contrary to most municipalities, Brix-Pedersen primarily thought of purchase from large scale systems to obtain this alternating current: Starting in the outer districts, the introduction of alternating current supply could follow the increase of demand, so that the decentral production capacity of the power station did not have to be expanded. The alternative option for rural utilities was to produce alternating current themselves. This had incidentally been used, but was according to Brix-Pedersen normally found too expensive.[11]

The problem got even worse, when the rural electricity sales exploded during the 1950s. By 1960 the Jutland association of rural utilities could observe that electricity sales of its remaining members had increased by no less than 860% since the association was founded in 1935. It briefly mentioned the causes of increased consumption in agriculture and rural households: With regard to agriculture, one might expect that the replacement of electrically powered threshing machines with harvesters combining reaping and threshing in the field decreased the electricity demand. But on the other hand, an increasing number of farms was electrified; in Jutland alone the share of farms with electric lighting connections increased from about half in 1935 to ninety-six percent two decades later, while the share of farms with power connections increased from about a third to seventy-seven percent. Moreover, there had come several new applications: Milking by hand was rapidly replaced by electric milking machines; while there had merely been 3600 milking machines in 1936, some 140.000 out of Denmark's 200.000 farms used electric milking in 1959. In addition, electric heaters were massively introduced as incubators and chicken brooders, while the electric blowers used in corn drying had a particularly large power demand - larger than that of the previous threshing machines for processing the same amount of corn. And with regard to rural households, new appliances included electric radiators for heating outside the actual heating season, while in the heating season the oil- or coke-fired central heating systems used electric blowers and circulation pumps. Finally, with regard to kitchen and entertainment appliances, the demand in rural households followed that in urban ones.[12]

Notably, representatives of rural utilities did not regret this increasing electricity demand, despite it causing technical problems for local electricity supply systems. On the contrary, they urged utilities to stimulate the growth of consumption. As Mondrup put it, the aim of rural utilities was to create a sale as large as possible within their supply area, regardless if electricity was produced decentrally or purchased.[13] In this context, the associations of rural utilities actively worked for the introduction of so-called 'modern and rational' tariff systems, which should invite consumers to increase their electricity consumption. Besides inviting several speakers at the associations, in 1951 they appointed a committee - containing the chairmen of the regional associations - to recommend a tariff system for small rural utilities, while a second recommendation followed in 1959 in the form of a consultant report.[14]

The change in tariff system followed the recommendations of a similar committee under the association of plant managers of town utilities, published in 1946. In the old tariff system, the electricity bill exclusively reflected the amount of electricity used, expressed in a kilowatt-hour price for lighting and power. In the new system, however, consumers paid large annual fees which should cover their relative share of the fixed costs of the utility (interest & repayment, maintenance, administration and part of the wages). On the other hand, they paid much reduced kilowatt-hour prices, which should only cover their share of the variable costs of the utility (fuel, lubricating oil, additional electricity purchases, part of maintenance and part of the wages). There was no distinction between light, heat and power consumption, so that each consumer could do with a single electricity meter; on the other hand, different consumer groups - households, industry and agriculture might have different prices (alternatively, consumer groups were defined by their maximum load). While the new system saved on electricity meters, meter reading and administration, the principle of large annual fees and low kilowatt-hour prices also invited consumers to increase consumption at disproportionally low costs. Indeed, experiences from other utilities had proven these tariffs remarkably effective in raising the electricity demand. They could also attract new industries, as such industries were not deterred by fixed fees, but by high kilowatt-hour prices.[15] During the 1950s a large part of rural utilities indeed followed the recommendation of their associations, and introduced these new tariffs - thereby increasing sales but also straining their supply systems.

Demands of industry and handicraft

Finally, representatives of rural utilities observed how a third important problem for local rural systems emerged particularly from the 1950s in the form of increasing consumer preference for alternating current supply. As Mondrup noticed in the first half of the decade, due to the decreasing role of direct current distribution in Denmark, the large part of modern appliances was constructed for alternating current supply. As a result, utilities could hardly tell consumers - often industries - to stick to direct current, and thereby refrain from modern appliances. He recommended that utilities prepared to supply both kinds of current; if not, large consumers might move their enterprises to areas, where alternating current was available.[16] By the end of the decade the situation had worsened: As the chairman of the Funen association said in 1959, the remaining rural utilities had to face the fact that in few years their consumers would demand alternating current supply, because direct current materials were taken out of serial production, and thus became increasingly expensive. In 1956 there had been 1,5 million electricity meters for alternating current in Denmark, towards less than 400.000 for direct current; in ten years, he expected, there would at most be some 100.000 direct current meters left, corresponding to some 60.000-70.000 consumers. Also he contended that the remaining rural utilities would be 'forced to change to alternating current supply', which normally meant electricity purchase from a larger system.[17]

The preference for alternating current supply was in particular expressed by rural industries concerned for their competitiveness. Already during the 1940s, discussions in industry and business journals signified an increasing preference for alternating current supply. One important motivation was that alternating current motors were cheaper than direct current motors, and required significantly less maintenance. In addition, following the general success of alternating current supply in Denmark and the rest of the electrified world, alternating current materials were much more standardized, tested and developed than direct current material. This particularly concerned press-button regulation: Following the general tendency to make machinery more independent of worker skills, much new machinery for special tasks contained press button regulation. Yet as such appliances were considered 'the least reliable step' in the production process, they required elements which were 'as much as possible standardized, mass produced and tested.'[18] In 1960, the jubilee publication of the Jutland association of rural utilities particularly emphasised that the increasing use of automatic controls in such machinery - for switching on/off or function regulation - directly affected the choice between direct current and alternating current supply in many small utilities, since 'almost all forms of automatics function better, more reliably or perhaps exclusively for alternating current.' Thus, it expected that within a couple of years consumers would demand alternating current supply from their utilities everywhere in the country, as current discussions in individual utilities already reflected.[19]

The future and history of local systems

As a result of these tendencies, by 1960 most spokesmen of rural utilities had radically changed their point of view upon decentral production. Some of them even describes the consolidation of such systems as deeply irrational. This view was perhaps best expressed by the new chairman of the Funen association of rural utilities, Ejvind Bjørn: Although there was much disagreement on the issue within the association as well as the single utilities, Bjørn went as far as to call rural electricity supply on Funen 'outdated'. The forty-two remaining members of the Funen association had a very low per consumer compared to the rest of the country; this was primarily due to a problematic supply structure, where 'prices were twice as high as they should be, and neither the voltage offered was as it should be.' This was so because 'we use local systems as we did fifty years ago, instead of rationalizing, as is currently done in all other fields of production'[20] With reference to economy, technical feasibility and increasing consumer preferences for alternating current, he found the end of local systems near.

While spokesmen of rural utilities thus changed their view with regard the current and future consolidation of decentral systems, their rhetoric of praising shifted focus from the current and future to the history of local systems. For instance, in his 1952 annual address to the association of rural utilities on Lolland/Falster, chairman Rs.

Pedersen accepted that 'developments go in the direction of alternating current.' He praised local systems on the countryside for having completed their important mission to 'teach people the advantages and use of electricity', and described their historical role as to 'pave the way' for centralized supply.[21]

This form of 'rhetoric closure' had often been attempted by advocates of centralized supply; indeed, already in 1905 professor Rung had criticised the feasibility of rural local systems, while at the same time praising Poul la Cour's efforts in developing such systems as one 'of the greatest importance for the country', because he spread the knowledge of electricity and its advantages to the rural population, which 'probably will be of great importance in the future.'[22] Since then, it had become a standard argument for propagators of centralized supply to emphasise that local systems had carried out an important task, but now should give way for a 'more rational' supply structure. Previously representatives of rural utilities had rejected this view of the development process, and asserted that local rural systems had their justification in the Danish electricity supply structure; in the 1950s, however, also they adopted this rhetoric, and provided local systems with the economic and technical irrationality relative to their larger scale successors, which became solidly entrenched also in the historiography of electricity supply.

Priorities of the interest organisations of rural utilities

This increasing acknowledgement of the advantages of electricity purchase by representatives of rural utilities is also reflected in the concerns and concrete work of the associations of rural utilities, which increasingly treated issues concerning the implementation of alternating current supply. This included for instance negotiations on behalf of the members with suppliers of alternating current electricity for additional purchase. Thus, after the often advantageous contracts of the Second World War (where the Electricity Commission of 1940 had assisted small utilities to obtain low prices from their suppliers) had run out in the late 1940s, the executive board of the association of rural utilities on Lolland/Falster engaged in negotiations with the suppliers on behalf of its members. Negotiations with the rural utility of Falster on the East Danish centralized system, which supplied the Eastern group its member utilities, led relatively quickly to agreement. Negotiations with the Nakskov municipal utility, which then supplied the Western group, were much more difficult, and demanded intermediation by the Electricity Council before new contracts were in place.[23] When the SEAS company took over supply in the area by the late 1950s, membership of the association had decreased drastically, and such negotiations took place directly between SEAS and the utilities.[24]

Likewise, in 1951 the chairman of the Funen association could report that negotiations with the new regional partnership Fynsværket had been its largest task. As a large number of its members purchased additional electricity, the association desired that its members could be included as a partner on similar terms with other partners. Concretely, the Funen association of rural utilities negotiated with the newly founded transmission company EFFLA mentioned above, and obtained an agreement, according to which rural utilities could join the company as members, or purchase additional electricity from it on advantageous terms.[25]

In addition to such negotiations, the associations of rural utilities also assisted in the partial or complete transition from local production to electricity purchase. In reply to a request for assistance by several members, in 1950 the national overbuilding of the regional associations appointed a committee (consisting again of the chairmen of the regional associations) to investigate the transition process from decentral production to supply with purchased alternating current.[26] This resulted in guiding lines for the transition process, which included the advice for individual utilities to prepare a ten years plan of demand, followed by an investigation of the supply options. It also addressed the financing of the transition to alternating current supply, which as we saw previously often proved a decisive hurdle. The report worked out by the association of plant managers in town utilities on the same subject the previous year offered little help: Municipal utilities had often accumulated capital, so that they were able to finance part of the transition costs for the consumer applications and installations. Rural utilities, by contrast, typically gave priority to low electricity prices to their members instead of the accumulation of capital, and therefore did not have this possibility. The rural association committee proposed that the consumers financed the change of those consumer applications, which had no professional function such as radios, vacuum cleaners and kitchen tools. The utility should finance the transmission system and the change of the direct current distribution system, consumer installations and consumer applications used in a professional context such as electric motors. Yet being consumer owned, this meant that the utility would take a loan on behalf of its consumers, and distribute interest and repayment over the consumers relative to their respective contribution to the transition costs.

By the mid 1960s, only few producing rural utilities remained, and the different associations had lost their importance. By then, the only surviving association was the one in Jutland; yet even this association had too few members left, and stopped the publishing of its newsletter. The newsletter of the plant manager associations had stopped several years earlier.[27]

New and old concerns in the decision processes

In the actual decision processes of individual rural utilities, the new concerns of consumer preferences and distribution problems were added to the old ones as economic feasibility and technical reliability. Decisions often involved an assessment of the relevance of these factors in the specific situation. The issue might be brought upon the agenda of the executive boards of the co-operatives after consumer complaints, or simply because the rapidly increasing production made an expansion necessary. Yet as the decision process normally involved discussion and a ballot in the general assembly, different motives and points of view often stood side by side.

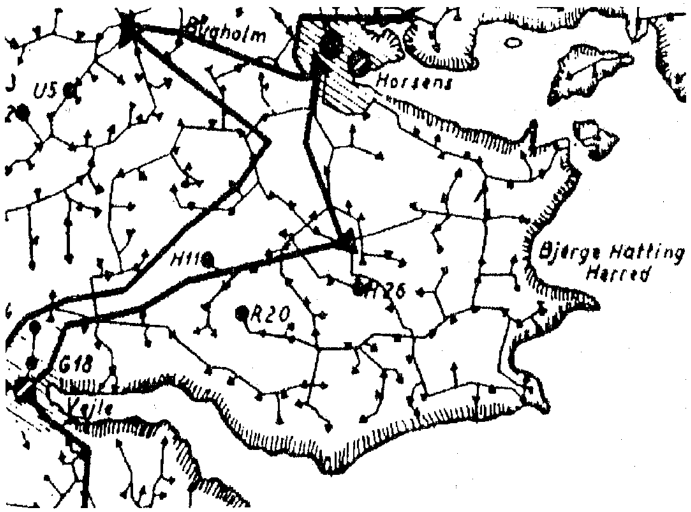
Four cases

The decision processes in the co-operatively owned utilities of Hedensted, Kongsvad watermill, Hammerum and Aså may be illustrative. In the case of the Hedensted in Jutland in the late 1950s, it were consumer preferences for alternating current supply that brought up the issue.[28] The local system in Hedensted consisted of a 500 kW power station and a 440 volts distribution system, and supplied some six hundred consumers. In addition, the utility was connected to the transmission grid of the area to purchase a small amount of alternating current for direct supply to some consumers (figure 10.1). But at a general assembly, local artisans and industrialists suggested a complete transition to alternating current supply, which would be of major importance for the local community: As factory director Hüttel put it in 1959, alternating current was an absolute precondition for attracting new firms to the small town, regardless if this alternating current was produced decentrally or purchased. Situated on the main road as well as the railway track between the Eastern Jutland towns of Horsens and Vejle, Hedensted was favourably situated for industry; moreover, as new industry in turn would be advantageous for local trade, handicraft and the municipality as such, it should be given the best possible conditions for settlement. This should include alternating current supply. Hüttel was backed up by other industrialists, and a local estate agent could report that industrial customers regularly backed out of a purchase, because it was supplied by direct current electricity. On the other hand, opponents of a transition to alternating current supply emphasised the high investment costs, and suggested that the utility perhaps should purchase additional alternating current in a seven years period, before taking a final decision.

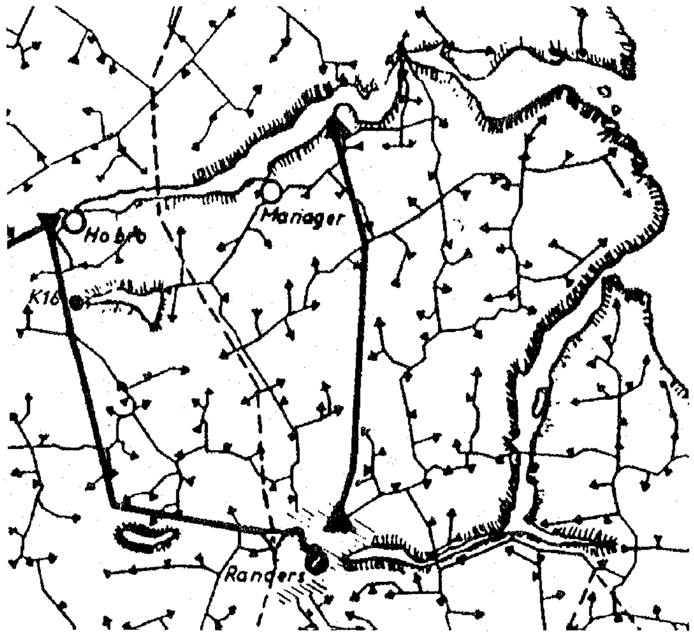
The assembly, then, was to decide for one of three options to meet the increase in consumption, which was nearly thirteen percent annually: An expansion of the decentral direct current production capacity with a new diesel engine; a gradual rebuilding of the local power station to alternating current production; or a solvation of the utility, and supply from the transmission company BHHH [*Bjerre-Hatting Herreders Højspændingsselskab*], in the supply area of which Hedensted was situated. The Hedensted consumers would be accepted in the BHHH company, which like the small utility was organized as a co-operative society of consumers. Moreover, as a member in the co-operative utility HOfV [*Horsens Omegns forenede Vandkraftanlæg*], which in turn was a partner in the Eastern Jutland partnership Skærbækværket, the BHHH company received its electricity from the centralized supply system at cost price. For the time being, the general assembly only decided to vote on the expansion of direct current capacity, which was rejected with ninety-six out of one hundred twenty-nine votes (76%). The decision between the purchase option and the option to decentrally produce alternating current electricity was postponed; the executive board was given the task to investigate this issue more closely, and should obtain an assessment from the Electricity Council.

While it thus was decided to follow the consumer preferences for alternating current, it was the economy of supply that was decisive for the assembly to opt for electricity purchase less than a year later. It was announced that the BHHH company could offer electricity at significantly lower prices than could be achieved with decentral production of alternating current. Moreover, the transmission company offered to rebuild the distribution network for alternating current and to build the necessary transformer stations. For the Hedensted local community, the transition costs were therefore limited to a change of the consumer appliances. Although a local shop keeper still argued for a gradual transition in a ten years period from decentrally produced alternating current to purchased power, the assembly accepted the purchase scheme with 133 out of 157 votes (85%).

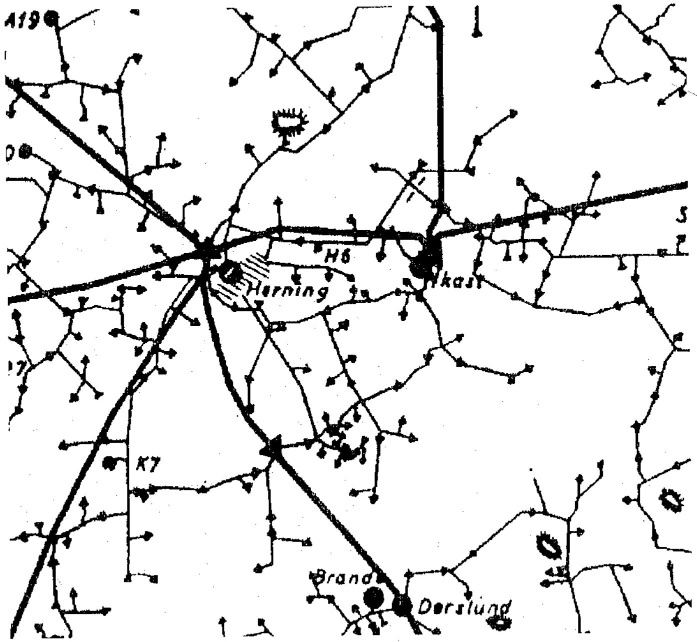
In the case of the Kongsvad watermill utility, it was the distribution problem that brought the transition on the agenda. The local system supplied some two hundred consumers in the villages of Handest and Glenstrup, situated between Randers and Hobro, through a 440 volts distribution network (figure 10.2). Power was partly produced by the small hydropower station (36 kW) at the Glenstrup lake, and partly purchased through a converter (140 kW). While the utility had chosen to maintain its local system in the early 1950s, in 1956 the general assembly finally decided for the transition to supply with purchased alternating current. As the chairman of the board, a local farmer, argued, consumers in the outer districts simply did not receive enough power. The board therefore suggested a change to alternating current supply from the new transmission company ELRO. Like BHHH in the Hedensted case, the ELRO company offered that to finance a new distribution network and five transformer stations to supply the area by alternating current. The consumers of the small utility would be accepted as members of ELRO without an entrance fee. Their only expense



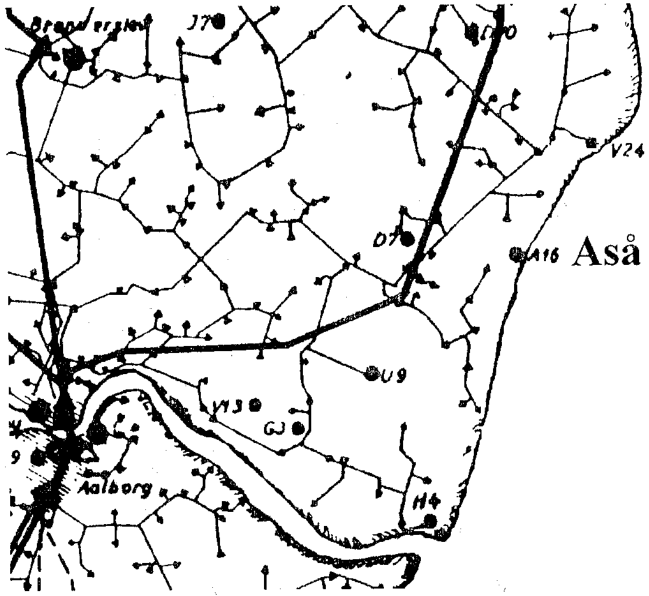
10.1: The Hedensted utility (H11) on BHHH's 10 kV transmission grid, which is in turn supplied by 60 kV from the Skærbækværket, in 1955. Source: Elektricitetsrådet 1957



10.2: The Kongsvad Mølle (K16) utility and ELRO's 10 kV transmission network, supplied fromRanders, in 1955. Ibid.



10.3: *The Hammerum utility (H6) on the 10 kV transmission grid of the Herning municipal utility, in turn supplied by 60 kV from Esbjerg, in 1955. Ibid.*



10.4: *The Aså (A16) and Dronninglund (D7) utilities and the 10 kV transmission network of the Nørresundby municipal utility, supplied by 60 kV from Ålborg, in 1955. Ibid.*

thus was the changes in consumer installations and appliances, and the offer was accepted by 34 against 24, which was sufficient in this case. By 1958 the transition to supply with purchased alternating current had been completed.[29]

In the case of the utility in Hammerum, situated near Herning in Mid-Western Jutland (figure 10.3), consumer preferences as well as distribution problems triggered a discussion on the transition to alternating current supply already in the second half of the 1940s.[30] The issue was presented to the utility by two groups of consumers: A group of 'large consumers' expressed their preference for alternating current, while some of the consumers furthest from the power station - those in the village of Birk, two kilometres from Hammerum - complained on the quality of supply over the 220 volts distribution system. As the growth of consumption would soon make an expansion of the supply capacity necessary, the executive board contacted the Herning municipal utility on its supply conditions for alternating current, and called in the general assembly to formulate a strategy. During this meeting, the traditional issues of economy and reliability were discussed: With regard to economy, the chairman of the board emphasised that the consolidation of the local system would demand both an expansion of the production capacity, and an upgrading of the distribution system from 220 to 440 volts. The expenses would match those of a scheme of purchased alternating current supply through two transformer stations, situated in Birk and in Hammerum respectively. The Herning municipality was one of the partners in the new Vestkraft partnership, and should be able to provide electricity cheaply. And with regard to reliability, the municipal utility of Herning promised to connect Hammerum directly to the town transmission grid, and thereby offer 'optimal reliability'.

The assembly then unanimously agreed that the board should work for a gradual transition to alternating current supply with purchased electricity. It started with alternating current supply of outer districts and of large consumers; thereby it met the consumer demands as well as avoided an expansion of its diesel power station. For about a decade, the utility then combined decreasing decentral production of direct current with the purchase and direct supply of alternating current. When direct current production had become insignificant in the late 1950s, it was decided to shut down the power station and rebuild it as a heat station for local supply of town heating.[31]

The fourth example of the utility of Aså in Northern Jutland, the consolidation of which was described in detail in chapter eight, illustrates how the old concern of reliability was a precondition for the purchase option. Although the utility had expanded its isolated local systems in the mid 1950s with reference to its economical feasibility and the superior reliability of the local system, by the late 1950s it foresaw that it soon needed a new expansion of its capacity due to the rapid growth of demand. In a discussion at the general assembly in 1959, representatives of local business - a factory entrepreneur, a mink farmer and an auction holder - argued for the introduction of alternating current supply, but met particular resistance from those who feared a decrease of the reliability of supply. According to its consulting engineer, engineer Sørensen of the firm Brix-Pedersen & Kamp Jørgensen, the price difference between purchase and decentral production was marginal; reliability therefore indeed was the decisive variable. In this case, the purchase scheme was designed accordingly: Aså would be supplied through two transformer stations, which were fed by two independent transmission lines from the North and South respectively (figure 10.4). When the transition was put up for vote, it was accepted with sixty-one out of ninety votes. In a following meeting of the general assembly, the parish official still expressed fear of reduced reliability of the purchase scheme: He also ran the local cinema, which had not had power cuts in eight years. Again, engineer Sørensen reassured the assembly by emphasising the ring system of supply.[32]

Even a previously sceptical utility as that of Aså, then, finally made the transition to alternating current supply. It did so despite the fact that centralized supply still was not decisively cheaper, and insisted upon the reliability of supply. A similar concern was discussed in the nearby utility in Dronninglund (see also figure 10.4), which decided for transition in 1961: Even though it were consumer preferences that made the transition to alternating current supply 'a necessity', it insisted upon supply from two sides according to the 'ring system' as a precondition.[33]

The importance of the new concerns

Decision processes in other rural utilities suggest that these cases are representative in several ways. First, the new concerns - and particularly that of shifting consumer preferences - were increasingly heard as an argument for the purchase of alternating current. While the argument had been mentioned in Hammerum in the late 1940s, by the mid 1950s Mondrup could observe that although many rural utilities expanded their decentral production capacity, and the utilities that abandoned decentral production primarily were the smallest utilities, a number of station towns had started the transition to alternating current supply - not in the least to satisfy local industry.[34] And in the second half of the 1950s, consumer preferences had become a standard argument in the decision processes. In Dybvad in the Vendsyssel region in Northern Jutland, a local electrician called the direct current supply for 'a direct hindrance for the establishment of new firms in the area.' But in most cases it were representatives from industry, who made the case, as in Hedensted and Hammerum above: In Ulfborg, for instance, representatives of local handicraft and industry wanted access to alternating current supply to make use of the increasing variety of specialized machinery and tools available for alternating current on the market. In Tjæreborg, it was the local the wood working industry which first applied to the utility for alternating current supply. And when the general assembly of the rural utility in Skals was to vote on a proposal for transition to alternating current supply, a local factory entrepreneur warned that a vote against alternating current transition was a 'first rank catastrophe, as it is most difficult for industries to obtain machinery and tools for direct current.' In this he was backed by another entrepreneur and a local smith.[35]

Yet, the preferences of local business representatives were not necessarily decisive in the 1950s. In the majority of rural utilities organized as co-operative societies, the such consumers would not have more influence in a ballot than other consumers. As they normally form a minority, they could not press through a decision. Wistoft (1994) points at this aspect as a decisive reason for the consolidation of small systems.[36] Instead, industrial consumers might have to wait until the 1960s, when also the market for household appliances strongly favoured alternating current. For instance, while the Dybtvad and Ulfsborg utilities -like the Hammerum and Hedensted utilities - indeed decided for transition to purchased alternating current, the utilities in Tjæreborg and Skals temporarily found alternative solutions. The Tjæreborg utility decided to purchase additional electricity from the transmission company of the area, which could be directly supplied to industry, while it was also used to satisfy the night demand for direct current of the utility through a converter. And in Skals, the proposal for transition was rejected with 30 against 117 votes at the general assembly. On request of local industry and with consent of the assembly, the board then worked out an arrangement with the transmission company of the area, so that consumers desiring alternating current could resign from the small utility and seek supply from the transmission company instead. Only several years later, in 1962, the consumers of both utilities voted for a complete transition to alternating current supply.[37]

A similar argument applies to the new concern of distribution problems. This argument was particularly heard in small utilities with a disproportionally large supply area, for instance utilities supplying several small villages, like the Kongsvad watermill and Hammerum utilities above. In the case of the utility of Fjaltring and surroundings at the West coast of Jutland, for instance, one third of all consumers lived in the nearby village of Ramme, and complained of voltage drops. As improvement of the distribution line to this village would be relatively expensive, a majority of the assembly voted for a purchase scheme, in which the supply area was covered from two transformer stations situated at the current power station and in

Ramme respectively. Yet the majority was less than the two-thirds required in the statutes to solve the company, and the utility it would combine purchase with decentral production for some years.[38]

Negotiation processes and the economy of centralized supply

It should be mentioned explicitly, that although a consensus upon the technical and economic superiority of centralized supply was rising also within the actor group of rural utilities, as late as 1960 nor this technical, nor this economic superiority was a matter of fact. With regard to technological performance, local systems maintained the advantage of reliability, unless they exceeded their economical supply areas. And with regard to economy, the above cases suggest that the cost margins separating the decentral supply and purchase options might be small. In such cases, the new concerns of consumer preferences or distribution problems would make the difference.

Two examples, where the annual expenses of the purchase scheme matched those of the decentral production scheme, are those of the utility in Ranum in the Himmerland region in Northern Jutland and that in Viuf in the hinterland of Kolding.[39] In these cases, the electricity costs would be equal, even though both utilities paid the full price for the transition to supply with purchased alternating current. The Ranum utility took a loan of seven hundred thousand DKK to finance the transition; interest and repayment were paid by the consumers via their electricity bills. And in the case of the Viuf utility, it was the transmission company [*Kolding Oplands Højspændingsforsyning*, KOH] that rebuilt the distribution network for alternating current, and also replaced all motors; but the consumers would pay for this through a doubling of the electricity prices for ten years.

In many other cases, however, the economic comparison either remained to the advantage of decentral supply, or small utilities found the gains of electricity purchase too small to start a transition. In these cases, the supply companies - mostly rural transmission companies - often made particularly attractive offers in order to change the comparison to the advantage of centralized supply. These cases suggest that the economic superiority of centralized supply was not a matter of fact, but often constructed in the negotiations between the actors.

Negotiation on prices

In general, larger utilities used two strategies to make electricity purchase economically attractive to the smaller utilities. A first strategy was to offer particularly low electricity prices, a strategy which also proved decisive in the decline of autoproduction (see chapter eleven). An early example is the rural utility of Møgeltønder, a village close to the Southern border and the Western coast in Southern Jutland, and thereby situated in the supply area of the transmission company EASV [*Elektricitetsforsyningen Andelsselskabet Sønderjyllands Vestkyst*]. The latter was a co-operative society of consumers, and a co-owner of the large Southern Jutland utility, from which it received electricity at cost price. When the Møgeltønder utility opted for purchase of electricity in the late 1930s, this followed a long negotiation process, in which the transmission company constantly reduced its prices. The transmission company explicitly used a pricing policy to increase its sales. Thereby it hoped to achieve an up-going spiral of expanding its supply at still lower prices: By offering low prices, it would increase the electricity sales; increased sales would help to repay the large investments in the large Southern Jutland power station and transmission network sooner; the lower fixed costs would then allow the low running costs of the large power plant to result in low electricity costs; and these low costs, finally, allowed the utility to again lower its electricity prices.

In the concrete case of the negotiations on supply to Møgeltønder, the latter in fact charged lower electricity prices than the EASV transmission company charged in the surrounding villages. Moreover, the small utility had already decided on an expansion. Still, the EASV company reckoned that the small extra sales would hardly affect its fixed costs, and electricity could therefore be offered rather cheap. Besides, it had already planned a transmission line passing the village, which could easily carry the extra electricity to Møgeltønder. It then lowered its prices until purchase became the cheapest option for the small utility, which then chose the purchase option.[40]

Negotiation on investment costs: The cases of Mørke and VOH

A second strategy was to participate in the financing of the transition of the local distribution network and consumer appliances to alternating current supply, as in the cases of the Hedensted and Kongsvad watermill utilities above. As Mondrup observed in the late 1950s, it often was the expensive transition to supply with alternating current that made the purchase option expensive, at least until the loans had been repaid.[41] Thus, also in this way larger utilities might intervene in order to change the comparison of the different supply options to the advantage of centralized supply.

The case of the small rural utility of Mørke may be particularly illustrative: Its consumers were pleased with its very low electricity prices, while the utility was represented in the negotiations by its treasurer - the local bank manager C.E. Jensen, who had been a leading critic of centralized supply in the Jutland association of rural utilities. Situated some twenty kilometres North of Århus, the utility was situated in the supply area of the large ARKE transmission company of the Århus hinterland. The latter was a co-operative society of consumers, and a partner in the Midtkraft partnership. Thus, while the Mørke utility relied upon its 600 kW diesel power station, the ARKE company received its electricity at cost price from the large 180 MW (1960) Århus power plant in the centralized system.

Since the mid 1930s, the Mørke utility and ARKE had repeatedly but in vain negotiated on the option of electricity purchase by the former. Such negotiations had failed as late as the mid 1950s, several years after the establishment of the Midtkraft partnership: The Mørke utility had desired to buy additional electricity, but ARKE had insisted upon a contractual obligation of the small utility to change to full alternating current supply within a ten years period. The individual consumers would then become members of ARKE, after they had paid the usual entrance fee to cover the costs of investment. However, the general assembly in Mørke rejected the ARKE contract proposal; while electricity prices would be similar as those in a decentral production scheme, the latter would avoid the large investment of the transition to alternating current as well as the decreased reliability. Instead, with the consent of the Electricity Council the general assembly almost unanimous decided for a decentral expansion of the direct current production capacity, which should be able to provide the demand until the mid 1960s.[42]

However, a break down of a small unit at the Mørke power station resulted in renewed negotiations, which ended with the massive acceptance of the purchase option around 1960. Notably, in this case of the replacement of the broken unit by another one, the Electricity Council and the Mørke utility completely disagreed on the economy of the different supply options: While the Council found the purchase option slightly cheaper (20,6 øre/sold kWh compared to 23,9 øre), C. E. Jensen found it much more expensive (34,2 øre/sold kWh vs. 19,7 øre). The deviating result partly followed disagreement on the number of transformer stations needed to supply the small town: The Electricity Council calculated with a single transformer station, while Jensen calculated with three of them (in the end, it was agreed that there should be seven).

But following this dispute, the Mørke utility accepted a new round of negotiations with the ARKE company, in which the latter made a large effort to make purchase more attractive than it was in the calculation of the Electricity Council. For instance, according to the resulting contract ARKE would rebuild the distribution network for alternating current, build the necessary transformer stations and provide new alternating current motors to the power consumers. Moreover, in the transition period the Mørke utility could purchase electricity from ARKE at a fixed and low price following the Midtkraft prices, but retained the right of decentral administration; the Mørke utility then decided maintain its usual, higher sale prices, so that it would run with a profit during the transition period, and accumulate a capital. Together with the income stemming from the sale of the power station and its equipment, this would be used to finance part of the change of the consumer appliances for alternating current. After the transition period, finally, the consumers could join ARKE without paying an entrance fee, and thus became co-owners of a valuable system for free. Hereafter, they would purchase electricity at common ARKE prices.

As a result of this offer, the economic picture had changed to the advantage of electricity purchase, also in the view of the Mørke utility. As a result, the general assembly now accepted the purchase scheme with a large majority of 129 votes against 19. Notably, this was a remarkable, but not an exceptional case of successful negotiation; instead, it was referred to as a 'school example of how the incorporation of a direct current system can be achieved smoothly and painless'.[43]

The will to negotiate and the strategy of negotiation of course differed from transmission company to transmission company. For instance, when the executive board of the small Jelling utility in Jutland compared the transition conditions of the Vestbirk transmission company [*Vestbirk Oplands Højspændingsværk*, VOH], in the supply area of which it was situated, with those of the nearby transmission company of the Vejle hinterland [*Vejle Oplands Strømforsyning*, VOS], it observed that only the former would participate in the transition costs. The latter - a co-operative society of transformer stations - invited village utilities to join as transformer stations, which meant that they kept local autonomy with regard to pricing, but also that they would have to finance the transformer stations and change the distribution network themselves. The Jelling utility could not make a free choice, however, as the transmission companies did not compete for consumers, but stuck to there own supply areas. Luckily, it was most satisfied with the offer of the VOH company.

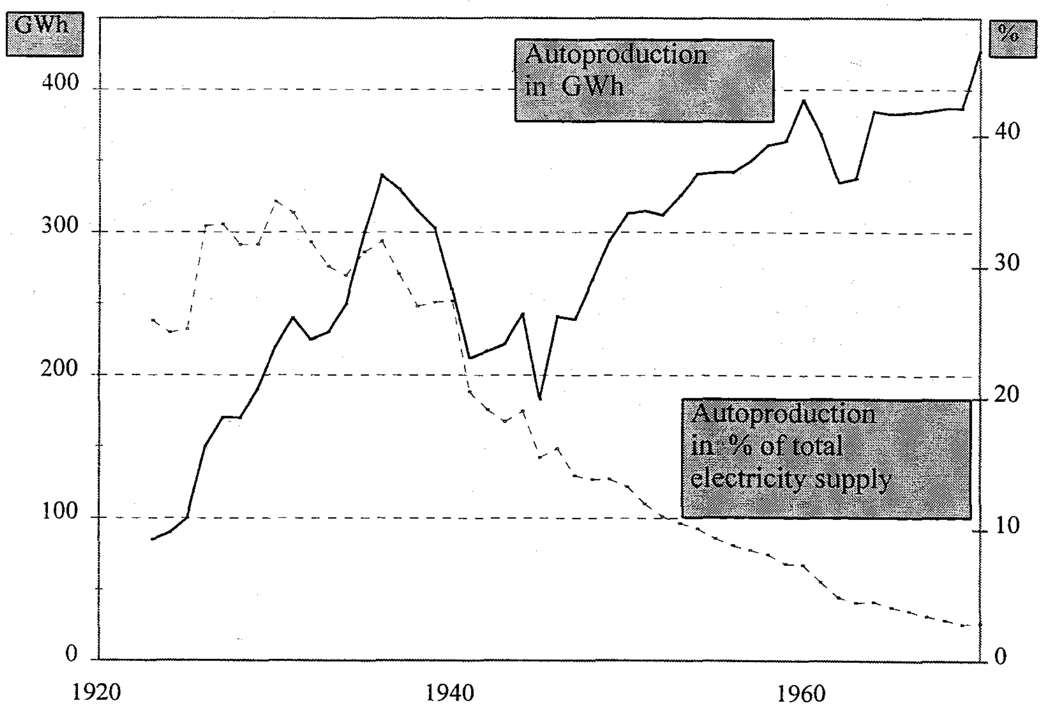
The VOH company, as its director explained at a meeting of the general assembly of the small rural utility of Tørring, could offer electricity very cheap, because its aim was not to earn money; like the small rural utilities it now sought to supply, it was a co-operative society with the statutory aim to supply the consumers in its supply area with electricity in the cheapest and best way. This was achieved by purchasing electricity from the centralized system, of which it was a co-owner via its membership of the HOfV utility, which in turn was an independent partner in the Skærbækværket partnership. Still, the VOH company negotiated with the small rural utilities individually in order to reach a satisfactory agreement on centralization. In case of the Tørring utility, which had a considerable dept, the VOH company would take over the distribution network and rebuild it for alternating current supply as well as build transformer stations without a fee. As a result, the consumers in Tørring would only pay for changes within their houses - installations and appliances. Yet also here the VOH company offered financial support by arranging cheap loans. In Jelling, the VOH transmission company would build three transformer stations, and rebuild the distribution network for alternating current, but for a modest fee of fifty thousand DKK. Both utilities were then dissolved, and the consumers joined the VOH company as members.[44]

When almost all small rural utilities abandoned their decentral production systems during the 1950s and 1960, they did not follow an ahistorical rationality, but anticipated a number of contextual factors - that is, factors external to the technical and economical feasibility of rural local systems, as it had been conceived in the 1930s and 1940s. The offers of purchase had become more attractive due to the technical and organisational construction of the West-Danish centralized system, the area where most remaining rural production systems were situated; small rural utilities increasingly dealt with rural transmission companies supplying electricity near cost price, rather than with municipal utilities charging a profit; the rapid growth of demand, following the general economic growth and technological modernisation of Danish society, made the capacity of low voltage, direct current distribution dissatisfactory; as the rest of the electrified world had already opted for alternating current supply, alternating current appliances became better and cheaper, and consumers increasingly wished to use these appliances; and, finally, larger companies made purchase particularly attractive by making special offers. Although the abandoning of rural local systems was massive and convincing, then, also here one can speak of a sociotechnical change, where social negotiation and contextual factors were an integrated part of the final success of centralized electricity supply.

11
The marginalisation of autoproduction

In an absolute sense, the autoproduction of electricity did not decrease during the period under consideration: Contrary to local and district systems, it remained stable in the post war period in terms of numbers, and it continued to increase in terms of electricity output. But relative to the rapid growth of public electricity supply, and particularly of centralized electricity supply, the importance of autoproduction of electricity was drastically reduced. In terms of numbers, autoproduction was dominated by farms, but only one percent of the electrified farms (1950) chose to autoproduce their electricity. And in terms of output, by 1970 even large scale industry (with twenty workers or more) included only forty-nine autoproducers, which produced merely twelve percent of the electricity consumption of this group.[1] Simultaneously, the output of autoproduction systems decreased rapidly relative to the total electricity output of Danish electricity supply systems, from some twenty-five to thirty percent in the 1920s and 1930s to merely seven percent by 1960 and three percent in 1970 (figure 11.1).

Figure 11.1: The dynamics of autoproduction output in absolute and relative to the total electricity supply in Denmark 1923-1970.[2]



Also in this case, an explanation of this decreasing importance should not draw on the technical-economic superiority of large scale supply in an a-historical and a-contextual sense. For chapter six showed, how autoproduction of electricity indeed could remain technically and economically rational in different contexts, and for many decades certainly was a competitive system. Instead, a point of departure may again be the actions and interactions of the relevant actor groups, as well as external developments changing the context of electricity supply, and the way in which these factors influenced the technical and economic feasibility of the different electricity supply options.

Autoproduction and utility pricing policies

The idea of pricing

An important factor, which increasingly changed the feasibility of the different electricity supply options for autoproducers, was the pricing policy of the electric utilities. Much earlier than in the case of the decline of local village systems, large utilities developed strategies to lure autoproducers of electricity into electricity purchase. It was already mentioned in chapter four how the even load of a power station had been recognized as a key variable by Edison in the 1880s, and was formulated in the concept of the load factor in the early 1890s. This understanding provoked explicit strategies of electric utilities to acquire a more even load, that is, attract consumers with different peak loads so as to even out the daily, weekly and monthly fluctuations in the load curve. One tool was the stimulation of the use of household equipment to increase the daytime load, in the United States from the 1920s. Another utility strategy from the turn of the century was to exploit electric traction, so that the daytime transport load could supplement the early morning and evening lighting loads. In a similar way, already during the 1890s leading actors in the new field of electricity supply argued for an active utility policy to contract industrial consumers, and thereby prevent the establishment of new autoproduction systems, or absorb existing autoproducers in the public electricity supply system.

For instance, in the late 1890s Clarence Feldman, then a leading engineer at the German electrotechnical firm Helios (later he became a leading figure in the electrification of the Netherlands), pursued the issue in the German electrotechnical journal *Elektrotechnische Zeitschrift*.[3] According to Feldman, in the future the load factor of electric utilities could be improved by introducing new consumption areas such as electric traction, cooking, heating and electrochemical industry. But in a short term, utilities should improve their load factor by attracting different types of lighting consumers. The instrument to this purpose was tariff policy: A detailed pricing system should give low electricity prices to attractive large industrial consumers, that is, consumers with a high utilization time of the equipment. By setting attractive prices, industrial consumers could be gained as utility customers, and competition from autoproduction systems be avoided.

In this argument Feldman followed the British pioneer on the pricing field, Arthur Wright, the manager of the municipal utility of Brighton. Wright had in the previous years developed a pricing system, where on one hand consumers paid a lower unit price relative to size of consumption (and the running costs of the utility), and on the other hand they might pay a capacity fee (covering the capital costs of the utility), which did not depend upon their maximum load, but upon their actual load during the peak hours of the utility. Thereby, the capacity fee reflected their real use of the generating capacity of the power station. Also the famous utility manager Samuel Insull, leading the rapidly expanding Chicago utility in the United States, was inspired by Wright when he developed his strategy and the declared aim to take over supply to the autoproducers of the area. In addition to pricing systems, he took up negotiation with the individual industrial firm to reach a contract of purchase, which was satisfactory to both parties.[4]

Arguments for negotiation and the success of NESA

In Denmark, this line of thought was adopted prior to the First World War by few large and progressive utilities. The point was for instance made by director Angelo of the NESA company in 1913, in an address to the Danish Electrotechnical Society.[5] Angelo had recognized that the consolidation of autoproduction systems often followed from their economical feasibility - they might provide electricity at lower prices than electric utilities offered (chapter six). This observation led him to argue for an investigation of, how far utilities could reduce their electricity prices to a level, where autoproduction was no longer feasible, and industrial firms would choose to purchase their electricity from an electric utility. In other words, utilities should show flexibility in their pricing with lower tariffs for large industrial consumers than for other consumers. Ideally, the electricity price should be just low enough to be acceptable for factory managers, but high enough for utilities to achieve 'an acceptable profit'. In Angelo's view, this meant that utilities should base their prices upon the cost price of autoproduced electricity. For if electric utilities could sell electricity close to the autoproduction price, factory managers would prefer purchase for a number of other reasons: They could use the capital and labour invested in power production in the actual production process, they would be relieved from the trouble of continuous expansions of the power department, and they would gain the possibility to keep part of the machinery running even though the main engine was down - without the disproportionally high running expenses of a back-up engine.

Moreover, as the conditions for autoproduction varied with a number of factors, including the utilization time and size of the system, its possible heat production and its distance from the power station (and thereby the costs of the transmission line), these tariffs should be determined for the individual factory in individual negotiations: 'Each firm should be treated individually with regard to its specific situation, and prices and other supply conditions specified in individual contracts.'[6]

In a broader perspective, Angelo expected that where large utilities offered electricity at sufficiently low prices, autoproduction systems would in time disappear. Once accomplished, this result would seem merely natural as a new stage in the ever increasing 'division of labour': Factories would concentrate on the production of their products, while electric utilities would specialize in power production. Electricity would become one of the raw materials, which factories could purchase in quantities that precisely followed the current size of their production.

Finally, Angelo observed that this development had hardly started in Denmark, whereas utilities in large industrialised countries like Great Britain and Germany were very successful at this point. Still, he could point at his own utility NESA, which within a few years had managed to contract a number of larger factories in the area. By the beginning of the First World War, when it had adopted the practice of special tariff negotiations for large consumers in return for long term contracts and guarantees on minimum purchases, it supplied some fifteen factories: About half of these were brick works, and the rest included clothing factories, glass works and gas works. Moreover, he could observe that factories, once they had started to purchase electricity, continued to do so.

Besides NESA, a number of other utilities quickly adopted the practice to negotiate special contracts with individual factories, or to work out tariff systems to attract special consumer groups. This included for instance the other large rural utilities on Zealand NVE and SEAS, the capital utilities of Copenhagen and Frederiksberg, and also a number of utilities in provincial towns: Already in 1914 the association of plant managers of town utilities, then nearly exclusively representing municipal plant managers, had discussed the advantages of negotiations with individual large consumers, and plant manager Olaf Westergaard of the Randers municipal utility had stressed the importance of exchanging information between municipal utilities on this matter, so that they were well equipped for such individual negotiation.[7] His utility was among the larger utilities that had adopted a pricing policy. And by the mid 1920s, a number of municipal utilities had individual contracts with large industrial consumers, including those of Esbjerg and Ålborg but also middle-sized and smaller ones such as Nakskov, Nykøbing on Falster, Silkeborg, Næstved, Struer and Kerteminde. Ten years later, also the municipal utilities of Kolding, Horsens, Helsingør, Hjørring, Fåborg, Viborg, Sorø and Åby used the individual negotiation strategy.[8] Finally, a number of municipal utilities charged particular low prices for single large consumers such as the Danish State Railways, and of course municipal enterprises such as water works and gas works. The large majority of town utilities, however, simply charged fixed prices according to the size of consumption or the utilization time, while most rural utilities had a single fixed power tariff.[9]

The utilization time argument in the 1930s

By the early 1930s, the matter was raised again by representatives from the large Copenhagen utility, which was concerned with the inclusion of autoproducers as customers of public supply utilities by means of negotiation and pricing policy. In a paper on the subject at the World Power Conference of 1933, Copenhagen utility director Johannes Børresen saw large autoproducers as a large potential market for public supply companies: In theory, the supply of existing autoproducers might double the electricity sales of the electric utilities. In practice, however, he admitted that utilities probably would be unable to compete with combined heat and power autoproducers, so the potential increase of the annual turnover was less.[10]

His chief engineer, Oscar Engholm, added in the *Elektroteknikeren* that the inclusion of autoproducers in public supply systems would not only increase the electricity sales, but also the utilization time of the utility, and thereby its economy of supply.[11] By actively working for an increasing demand stemming from household, agriculture and electric traction, Danish utilities had achieved a utilization time of the generation capacity of between one thousand and three thousand hours (a load factor between 0.12 and 0.35). The absorption of large scale industries would further increase the utilization time of the utilities. Therefore he regretted that many Danish utilities had neglected the field of large scale industry: The gross profits of supply to small consumers were so high, that they often were uninterested in customers, which only gave lower profit margins.

To illustrate how far the improved utilization time allowed a utility to decrease its electricity prices for a large industrial consumer, he considered the example of a machine factory with a daily operation of eight hours, including the peak hour of the power station in the late afternoon. From experience it was known that such a factory had an irregular power demand, and might reach a utilization time of the generation capacity of some one thousand hours only. If it was the only consumer of the utility, the production costs of electricity were at least ten øre per kilowatt-hour (four øre in running costs and some six øre in fixed costs). However, since the machine factory was but one consumer among many, its electricity load evened out that of other consumers, and the actual production costs of the utility decreased in two ways. First, the peak load of the factory might fall at a different time than the peak load of the utility: The machine factory might draw its peak demand between ten and eleven o'clock in the morning and two and three o'clock in the afternoon, and during the peak load of the utility in the late afternoon, it might only demand half of its maximum load. As a consequence, to supply the factory the utility only had to increase its generating capacity with half of the maximum capacity of the factory. In Engholm's calculation, this meant that the fixed costs of supply were reduced to three øre pr. kilowatt-hour. If the running costs remained unchanged, the real production costs of the utility had decreased to seven øre/kWh.

Second, the utility might supply several factories with a similar low utilization time of the generating capacity, but different peak times. If there were ten other factories, their maxima would equal out, and their common utilization time increased for instance by a factor two. In this case, the fixed costs would decrease to 3,5 øre/kWh and the running costs to 2,5 øre/kWh, together some six øre/kWh. In sum, the production costs of the utility would be significantly lower than those expected on basis of the maximum load and utilization time of the factory.

According to Engholm, this lower production price of supply to large industrial firms should primarily be to the advantage of the large consumers: The utility should adapt its pricing policy with the particular aim to develop acceptable yet competitive prices, meaning that it should reduce its prices and accept lower profits per unit of electricity sold, but on the other hand be able to supply large scale industry. Moreover, in using different tariff forms there should be room for negotiation sensitive to the particular characteristics of the autoproducers concerned.

Pressure from industrial organisations and post war pricing reforms

The large majority of municipal utilities and small rural utilities, however, had not innovated their pricing strategies by the Second World War. As mentioned in chapter six, NESA director Angelo still observed that electric utilities in general earned too much on their sales to make purchase an attractive option for autoproducers. But now the issue of utility pricing was also taken up from the side of industry, which tried to press in particular the municipal utilities - which still dominated the supply business - to develop 'more reasonable' prices for industry. This resulted in several conflicts between interest organisations of utilities and those of industry, which coincided with the growing concern of utilities to reform their tariff policies with regard to large consumers.

Shortly after the Second World War, spokesmen of Danish industry developed a strong argument against what they considered as too high prices, particularly by municipal utilities. For instance, Anton Ranløv - previous secretary of the industrial interest organisation the Industrial Council [*Industrirådet*] and now director of the association of Danish flour factories [*Foreningen af Danske Handelsmøller*] - put up the issue in a broader perspective of post war reconstruction, where Danish industry should be given favourable conditions in order to acquire a competitive position. For with the return of peace, the concern for costs and competitiveness of Danish industry and trade returned as 'decisive factors for the survival of individual firms as well as entire industries.'[12] As a result, also the cost of electricity again came in focus, particularly for those industries for which power costs constituted a significant part of the production costs. According to Ranløv, industry was in general dissatisfied with the electricity prices set by electric utilities: The prices were too high, partly because municipalities exploited their monopolies to indirectly tax their consumers, while tariff systems were too heterogeneous throughout the country, and gave similar firms different competitive situations. The irrational confusion in pricing policies of Danish utilities thus decreased the competitiveness of Danish industry.

Few months earlier, Niels Lichtenberg of the Industrial Council had made a similar complaint.[13] He stressed that in principle industry did not desire to autoproduce its power, but was often 'forced' to do so as electricity prices were too high or electricity was used for indirect taxation. He desired a closer relation between the production costs and the prices of electric utilities, and at least business firms should not be plagued by indirect taxation. For the time being, the situation was not very good. It was best in the supply areas of the three large district utilities on Zealand and that of Southern Jutland, which had flexible pricing policies. Even the Copenhagen utility, which was comparatively cheap in technical current supply, had a too high prices for large consumers. In sum, 'it was up to the electric utilities themselves if the ongoing rationalization should include industrial power supply.' If municipal utilities lowered their prices, Lichtenberg contended, industry would immediately start to purchase its power.

As a result of the pressure from spokesmen of industry, in 1946 the association of Danish utilities and the association of (urban) plant managers appointed a joint committee to work out common utility guidelines for tariffs for electricity supply to industrial firms. The focus was exclusively upon large consumers with an annual electricity consumption larger than one hundred megawatt-hours. Its report, published in 1948, followed the earlier suggestions by recommending that electricity prices should better reflect the actual production costs of the utilities, and proposed a tariff system which allowed for this - including a tariff for the real occupation of the generating capacity. A comparison of the costs of industrial autoproduction of electricity with purchase following this tariff system suggested that modernly equipped utilities could supply electricity cheaper than new autoproducers. Even for autoproducers with a high utilization time of 4500 hours, purchase would be cheaper for capacities smaller than one megawatt. Finally, the report explicitly stated that the municipal concern of electricity supply profits was not included in the investigation, although the committee did suggest that utility profits 'should be modest.'[14]

The Industrial Council, which had appointed its own electricity tariff commit-tee to study the pricing policy of utilities towards industrial consumers, largely accepted the conclusions of the report. Yet, electric utilities did not necessarily follow the recommendations of their interest organisation. In the early 1950s, director Angelo observed that the success of centralized supply also in West Denmark indeed facilitated reduced electricity prices for industry.[15] Technically, the concentration of production in large scale and modern production machinery facilitated low production costs ab power station. And organisationally, the ownership form of private production partnerships eliminated municipal profit concerns from the power production and enabled electricity supply at cost price. Apart from minor variations in population density in the different supply areas, which influenced the costs of transmission networks relative to the number of inhabitants, this should ensure quite uniform prices. Still, the problem of profit margins remained within municipal distribution companies, and Angelo once more argued that electricity should be supplied without large profits - preferably without profits at all - to Danish business firms, which increasingly would compete with other countries having lower electricity prices than Denmark.

At the same time, the Industrial Council continued to work for lower electricity prices for industry. For instance, in 1950 it approached the Copenhagen utility to urge it to supply industry at cost price, which resulted in new and lower tariffs introduced three years later. Also in 1950, the Industrial Council asked the Minister of Trade to urge reluctant electric utilities to supply industry at the lowest possible prices. Still, in 1954 the director of the Industrial Council, Axel Odel, observed that many industrial consumers still paid high prices due to the profit margins of municipal production or distribution companies. In addition, utilities might still charge prices based upon the maximal load of factories, rather than upon their real load, and thus kept the advantages of load management for themselves.[16]

However, although spokesmen of industry continued to complain that 'in a number of cases municipal taxing still exists', by the late 1950s this was not a main concern anymore. Municipalities increasingly competed in attracting new industries, and therefore reduced their electricity prices.[17] Many municipal utilities did follow the recommendations of their interest organisation and introduced 'fair tariffs' for large industrial consumers, and also reduced the indirect taxing of electricity. By 1958 the chairman of the association of municipal utilities, Marinus Larsen, observed that 'the time that electric utilities are used for tax objects is largely gone.' And as his successor Hans Bagge put it at the annual meeting two years later, 'municipal electricity taxing is old-fashioned, modern municipal politicians recognize the importance of low municipal electricity prices.'[18] In half a decade, the active utility strategy of pricing and negotiation had spread from a minority of utilities to a general practice, and made centralized supply increasingly competitive relative to autoproduction.

From autoproduction to purchase in the flour industry

General background

How did such utility strategies affect the different industries? A first case to illustrate the success of the purchase option is that of the flour industry. In the time period under consideration, there remained around forty flour factories (flour producers larger than five workers) in Denmark. Dependent on transport facilities for corn, flour and fuel on one hand and large urban markets on the other, flour factories were often situated in the harbours of middle sized and larger towns, and thus situated in the supply areas of municipal utilities. Moreover, the flour industry was among the most energy-intensive Danish industries, and by 1950 also one of the most electricity intensive industries (table 6.1). Yet it differed from other electricity-intensive industries in purchasing virtually all its electricity.

The early electrification of the Danish flour industry was briefly mentioned in chapter two; from the late nineteenth century flour factories had adopted autoproduction systems for electric lighting, not in the least because electric lighting reduced the danger of fire in these fire-prone establishments. On the other hand, flour factory entrepreneurs were reluctant to install electric drive. According to agitators for electric drive, in the 1910s they were far behind other industries in this respect.

This peculiarity was related to the specific physical context of industrial flour production.[19] Flour factories were often high, multi-stored buildings (five-stored buildings were not uncommon) flanked by similarly high storage buildings or silos. In a modern flour factory of the turn of the century, at least four departments with a typical set of machines could be distinguished. First, the silos for grain storage contained automatic scales of balance weighing the incoming grain as well as cleaning machines for initial cleaning, for instance ventilators removing dust and sand by suction (and later shaking grates removing larger stones etc.). Second, the actual cleaning department, often at the top floor of the factory building, contained machines for removing dust (ventilators and brushing machines), seeds and some small stones ('trieurs'), metal pieces (magnets) and a wet cleaning machine removing sponged grains and remaining stones. Third, the grinding department was made up by roller stands and bolters alternately. Flour was extracted after each grinding step, and the remaining particles grinded further. In this way, a high grinding efficiency could be obtained. And finally, on the ground floor flour mixing machines and packing machines prepared the product for transport. In addition to these machines, the entire process of mass-producing flour had from the very beginning depended greatly upon transport machines like elevators and Archimedean screws, which transported the grain and flour from machine to machine and from department to department. This enabled a continuous flow, in which human interference was eliminated as far as possible. Consequently the flour industry, like the paper and cement industries, was extremely capital intensive, and also flour factories were in operation day and night (generally with the exception of Sundays and holidays).

Finally, rotary action to all these machines, of which the grinders were most power demanding (consuming approx. three-fifths of the factory power demand[20]) was normally provided by a large, central steam engine of some hundred horsepowers around the turn of the century. In addition, there might be back-up engines and some small special purpose engines. From the main engine in the basement or the engine house, power was transmitted to the different floors of the factory by means of a vertical main shaft. At each floor, power was taken and by shafts and belts provided to groups of machines with similar power requirements. The factory therefore had a cleaning floor, a sieving floor and a grinding floor. In addition to the main shaft, separate belts might transmit power between the floors, for instance from the steam engine to some fast revolving cleaning machines.

Autoproduction of power and the slow electrification of the flour industry

It was because of the interdependence of the different machines and the continuous operation of the factory, that flour factory entrepreneurs regarded their factories as 'one large machine' and doubted the benefits of electric drive in the 1910s. The continuous operation and steady power demand reduced the specific economic or technical advantages of electric individual or group drive. Moreover, the introduction of many electric motors in all corners of the dusty factories would introduce new possible sources for break-downs, which would stop the entire factory. As continuous operation was the main economic factor in the flour factory, flour factory entrepreneurs chose to maintain the reliable power transmission by line shafts; and as the advantages of electric motors for line shaft drive over steam and diesel engines were minimal, they remained autoproducers of mechanical power.[21] Finally, like small rural utilities flour factory entrepreneurs feared for blackouts in public supply systems using high voltage transmission, which per definition were beyond the control of the factory, and for which public supply companies were unwilling to accept responsibility. Reliance upon such power suppliers, then, was incidentally depicted as 'an evil, which is accepted as a matter of course in our modern times of centralisation.'[22]

In the following decades, also the arguments of cheap autoproduction of power due to a high utilization time and even of combined heat and power production were heard. The application of steam for heating cannot be compared with that of paper factories; still, flour factories did require significant amounts of heating for the drying of the grain after the wet cleaning process, as well as for the conditioner, a new machine for exactly regulating the moisture content of the raw material before grinding, and to a lesser degree for factory heating. If the flour factory thus chose to purchase its power in the form of electricity, it might still need to maintain its steam boilers for heat production. An example is the flour factory in Nykøbing on Falster, which only started to purchase electric power after the Second World War, but still maintained its steam boiler for heating purposes.[23] And with regard to the utilization time, the continuous operation of the flour factory and all its machines gave a steady power demand: In the 1940s, it was argued that flour factories might have a utilization time up to 5600 hours annually (a load factor of 0.6). Hence not only the autoproduction of mechanic power was cheap, but also the autoproduction of electric power - an argument, which, as we shall see below, was used in negotiations with the electric utilities.[24]

In view of these arguments, it is not surprising that flour factories still massively opted for autoproduced power at the eve of the First World War - only ten percent of the consumed power was electric, and most of this was probably autoproduced. And although there certainly occurred a transition to electric drive, this transition took some four decades, and a number of factories continued to autoproduce mechanical power until after the Second World War.[25]

Flour factory power and electric utility economy

However, already in the 1910s agitators for electrification had related the economic feasibility of electric drive in the flour industry to the pricing strategies of electric utilities. They recognized that the customary arguments for electric drive, which were accepted by so many other industries, were insufficient to convince the flour industry. Yet they insisted that these arguments were important, and if flour factory entrepreneurs and technicians did not accept them, it was attributed to their short-sightedness. For it were the *indirect* savings in power costs that made electric drive economically feasible in the flour industry:[26] These indirect advantages not only included the possibility of individual drive to turn off idle horsepowers. First, flour factories were in an extreme degree designed after the power flow, while electric individual drive would enable a more rational design according to the product flow. Second, electric motors produced more steady power than other engine types, which for flour factories was particularly important in the aspirators (ventilation machines) in the cleaning department, which demanded rather precise regulation of the speed of the air stream separating the dust from the grain. Third, this steady drive would also facilitate a more steady grinding and sieving process and thereby a higher productivity as well as a better product. And finally, electric drive enabled the measuring of power losses: Often, roller stands would be in need for re-grooving and cause major power losses, which were not easily identified. In an electric power transmission system, however, an installed ammeter would immediately indicate the increased power consumption of such a roller stand.

But as these arguments were insufficient to convince flour factory entrepreneurs of the economical feasibility of electric drive, agitators of electric drive were early to point at reduced electricity prices as an alternative strategy of seduction. Following the line of argument of progressive utility representatives, they suggested from the early 1910s that flour factories and electric utilities should develop a co-operation beneficial for both parties. For electric utilities seeking new and attractive consumers, flour factories seemed a most natural choice, as their steady and large power demand enabled utilities to supply electricity 'at a very low price and still profit from it.' In return, flour factories 'could expect electricity prices, that were significantly lower than those of other customers.'[27] Under such circumstances, it was argued, even the largest flour factories might be electrified with purchased power, as examples of foreign flour factories illustrated. Thus the economy of the electric utility and that of the electrification of the flour industry were tied together; it is also in the light of this double concern for the diffusion of electricity in society, that the irritation of the electrotechnicians about the slow electrification of the flour industry is understandable.

Pricing policies and the success of the public supply system

The gradual electrification of the flour industry in the following decades coincided with a nearly complete purchase of electricity (table 11.1): By the mid 1930s some sixty percent of the power consumption stemmed from purchased electricity, while power consumption of autoproduced electricity was negligible. And after the Second World War, the share of purchased electricity in the power consumption had increased to eighty-four percent, while the share of autoproduced electricity was still marginal. To these figures, the statistics of industrial production add that the share of autoproduced electricity in the electricity consumption of flour factories was reduced from merely seven percent in 1940 to a marginal one percent in 1951.[28]

Table 11.1: The power sources of flour factories, including special purpose and back-up engines.[29]

	Nr. of factories	Steam engines		Oil engines		Gas engines		Electric motors (autoproduced electricity)		Electric motors (purchased electricity)		
		nr.	hp.	nr.	hp.	nr.	hp.	nr.	hp.	nr.	hp.	% of hp.
1906	32	35	3.321	1	50	5	163	0	0	0	0	0
1914	42	27	2.669	20	2.164	6	153	-	-	30	531	10%
1925	64	20	2.574	33	3.352	5	184	-	-	253	3.998	40%
1935	42	16	2.203	20	2.228	1	100	17	834	553	7.817	63%
1948	47	2.649 hp.						224	1.589	1.147	13.797	84%

Moreover, from the beginning negotiation between flour factory and electric utility played an important role in this transformation. For instance, one of the first Danish flour factories to adopt all-electric drive was a newly established flour factory in Svinninge on North-Western Zealand in 1916 (figure 11.1). This factory was not only placed centrally in a corn producing rural district and near the transport facilities of the Svinninge railway station, but also in the heart of the supply area of the large rural utility of North-Western Zealand NVE, which then operated its district system from a power station in the same small town. The NVE company negotiated directly with the factory on power supply, which resulted in what was described as 'supply conditions, which were very advantageous for the flour factory.'[30]

The factory, which had a production capacity of one hundred and fifty barrels of wheat per hour, was equipped with the available modern machinery, which was powered by electromotors in a system of group drive: In the corn silo building, an eight kilowatts electric motor powered the transport belts, elevators and an aspirator. In the cleaning department at the third and top floor of the main building, an eleven kilowatts motor powered another aspirator, a trieur, an electromagnet, a brushing belt and a roller stand for initial crushing. At the grinding department, a larger thirty kilowatts motor powered the so-called midget grinders (multiple grinding and sieving machines), a smooth roller stand and another aspirator. And finally, at the packing department a small four kilowatts electric motor powered the flour mixing machine.

Also other flour factories, which adopted all-electric drive in the 1910s, might benefit from special tariffs from the electric utilities of the area. Among these was the flour factory 'Olympia' in Randers, which likewise adopted all-electric drive in 1916, and which received its power from the municipal supply company of Randers according to a specially negotiated contract.[31]

Other flour factories followed in the following decades, and in the Second World War the issue of pricing was explicitly raised by flour industry interest organisations. For on one hand, the fuel shortages of the War forced many remaining autoproducing flour factories to approach the electric utilities for power supply. The flour factory in Slagelse is an example. This flour factory had installed a small (two kilowatts) autoproduction system for electric lighting in 1903, but maintained the autoproduction of mechanical power since; in the 1930s, electric lighting still was the only application of electricity in the factory, although it had been connected to the municipal power station, probably for back-up in case the main steam engine was shut off. But in 1939 it applied to the Slagelse municipal utility for electric power supply, and when a transformer station was placed at the factory premises, the factory disposed of its autoproduction installation.[32] In Copenhagen, likewise, the Blegdamsmølle and Havnemølle flour factories applied for electric power supply from the municipal utility, along with some fifty other middle-sized firms in the beginning of the war. Typically for the emergency solution, they did not exploit the well-advertised advantages of electric group or individual drive; for the time being, they maintained line shaft drive powered from one central electric motor.[33] As a result of the fuel situation, then, spokesmen of the flour industry might find flour factories 'committed' to the municipal utilities with their monopoly power stations, and therefore protested to the often one-sided determination of electric power prices without taking their consumer characteristics into account, and also to the inclusion of a large profit margin to balance the municipal budget.[34]

A second reason for protest followed the government regulation of the flour prices in order to secure cheap bread for the Danish population. The maximum flour prices were calculated on the basis of the cost of production, particularly the cost of grain, but also including the average costs of electric power. The problem, therefore, was not only that the electricity prices were high, but also that they were very different around the country, which was at least partly due to the heterogeneity in tariff systems and pricing strategies of the utilities. The association of Danish flour factories conducted an investigation on this matter, which showed that its members paid kWh prices from less than ten to more than eighteen øre; moreover, although the single utility might consider the size of consumption in its pricing, and flour factories always paid lower prices than smaller consumers, the comparison showed that on a national scope large consumer might pay much higher prices than a number of middle-sized and smaller flour factories. According to a spokesman for the flour industry, this fact indicated that municipal utilities had managed to keep the Price Control Council [*Priskontrolrådet*] at a distance: If a standard piece of Danish soap cost ten øre in one town, fourteen in another and eighteen in a third, the Price Control

Council would certainly intervene. But concerning the sale of kilowatthours - certainly also a standard product - the price difference was accepted. As flour prices were regulated but electricity prices were not, the possibility for an economically feasible production was different from flour factory to flour factory. As power costs might constitute up to twenty-five percent of the production expenses of flour immediately after the war in 1945, such differences obviously affected the production costs. As it was concluded, 'flour factories are helpless against high power prices, until they again may run electric autoproduction systems.'[35]

The critique of the association of flour factories led to the negotiation between several of its members and the utilities of their areas.[36] And in 1946 it was observed that although negotiations generally resulted in only small price reductions, municipalities increasingly understood that electricity was a product, and not a tax object. An editorial in the flour factory association's journal reminded the members, that they had a strong negotiating position, as there hardly existed other electricity consumers with such attractive supply characteristics as the flour industry. But the same characteristics that made flour factories attractive customers for public supply companies, also made that they 'would not hesitate to erect autoproduction installations, in case public supply companies cannot or do not want to recognize the value of flour factory customers by offering favourable electricity prices.'[37]

An example of a factory, which took this consequence, was the Munke Mølle flour factory in Odense, one of the largest flour factories in Denmark. This factory had erected an autoproduction installation for lighting on its new premises in 1905, but had preferred to buy its electricity from the Odense municipal supply company by the early 1930s. During the Second World War, however, the factory problematised the relatively high electric power prices of this utility, and urged a 'more fair pricing policy', while it also investigated the possibility to start an autoproduction of electric power. In 1943 the factory, with a maximum power demand of half a megawatt, purchased a new combined heat and power unit with a power capacity of four to six hundred kilowatts. The motive was that the 'negotiations with the Odense municipal utility had not resulted in a satisfactory contract on electricity supply.'[38] Negotiations continued, in which the Odense municipal utility indeed reduced its prices slightly[39], but new negotiations immediately after the war failed. The factory put up the condition that the electricity price should not exceed the costs for which the factory could autoproduce its electricity.[40] Although the municipal utility expressed the will to negotiate, it would or could not meet this demand, and from 1946 the factory put its new autoproduction installation in operation. The link to the public supply system became a back-up only. With reference to the pricing policy of the public supply company, then, a relatively small autoproduction plant was judged more economical than supply from the nearly fifty times as large (nearly thirty megawatts) Odense public power plant.[41]

In 1949, however, the public supply situation changed with the establishment of the Fynsværket partnership, in which the Odense municipal supply company participated. This company would soon erect a new eighty-two megawatts power station, and the available capacity and low running costs probably allowed the Odense municipal utility to offer more advantageous electricity rates to the flour factory: In 1950 the Munke Mølle factory shut down its power plant, and expressed the intention only to purchase electricity in the future.[42]

Electric drive in the butter industry

A second case of particular interest is that of the butter industry. In Denmark, there remained a large number of butter factories during the entire period under consideration. There were over fifteen hundred factories in the 1920s, and by 1960 there were still more than one thousand. Only in the following decades the rationalization process in the dairy industry would accelerate.[43] These many butter factories, which also might have a cheese production, were primarily scattered around in the countryside, and thereby situated in the supply areas of rural production companies, transmission companies or municipal utilities exploiting hinterland supply systems. But as described in chapter two, a substantial part of these butter factories adopted autoproduction systems for electric lighting, and thereby at an early stage became a leading industry in the diffusion of autoproduction systems. But like flour factories, butter factories eschewed to use electricity for driving machinery. The main argument was the cheap co-production of heat and power, which was possible due to the large heat demand of pasteurizing the skim-milk and the cream, but also of cleaning purposes, washing bottles etc.

But from the 1930s, butter factories began to shift from steam drive to electric drive, and by 1960 it was observed that autoproducers of mechanical (or electric) power had largely disappeared, and 'only few butter factories still maintain a steam engine.'[44] Only the steam boiler remained, but was exclusively used for heat production. Within several decades, then, autoproduction of steam power and possibly electric lighting had been replaced by the purchase of electric light and power.

The failure of (purchased) electric drive in the 1910s and 1920s

Although electric drive was only rarely adopted before the 1930s, agitators of electric drive had listed a number of reasons why electric drive supplied from an electric utility should be advantageous, and indeed electric drive had been on the

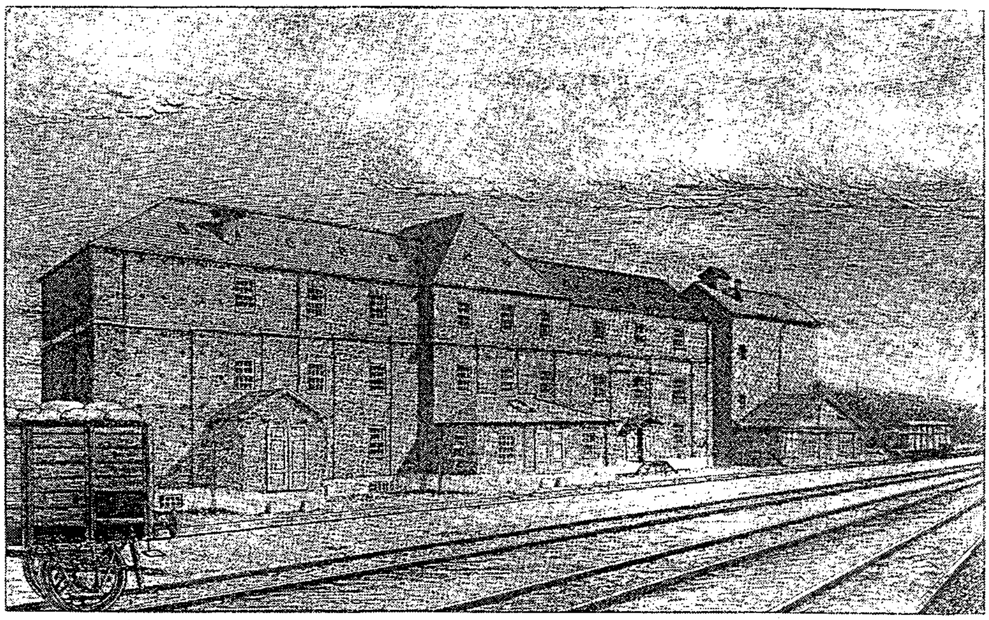


Figure 11.1: The electric flour factory in Svinninge on Zealand by 1929. The factory consists of a main building (left) and a corn silo of some fifteen meters hight (right), and lacks the large chimney, which previously had been characteristic for flour factories. Source: Den danske møller. Tidsskrift for dansk mølleindustri Vol. 2 (1929), nr. 5.

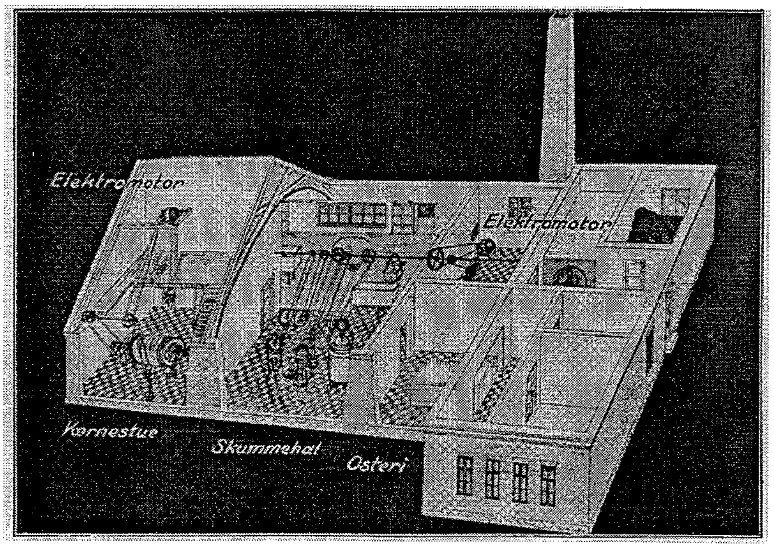


Figure 11.2: Electric drive of a butter factory in a propaganda brochure of the association of Danish utilities in the late 1920s. Two electromotors drive a belt for the churn and a line shaft for the separators respectively. Source: N. J. Andersen 1928, 76.

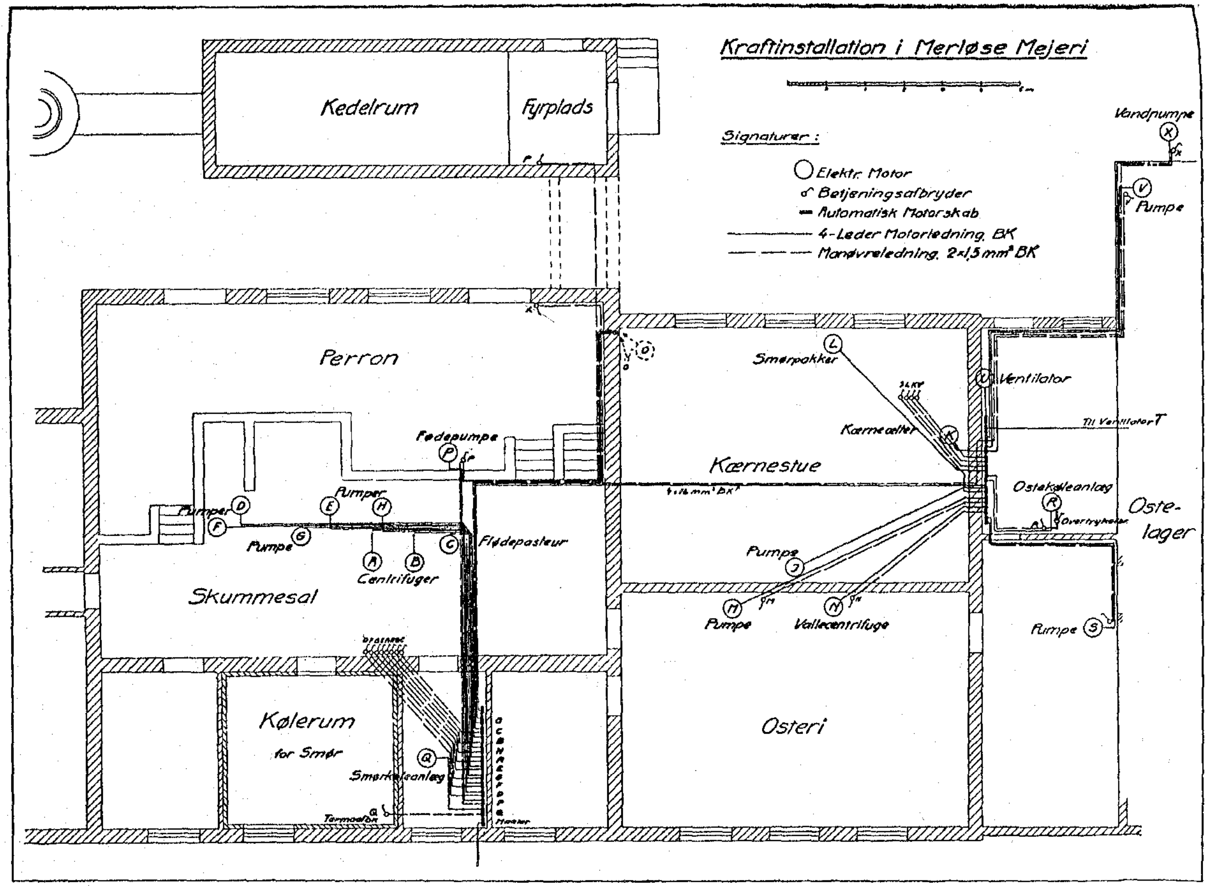


Figure 11.3: Electric single drive at Merløse butter factory in the supply area of NVE, from which power was purchased. The butter factory consists of a small boiler house [Kedelrum] and a main building with skimming hall [Skummesal], churning room [Kærnestue], butter cooling room [Kølerum] and cheese production room [Osteri]. Electricity entered the building at the southern wall, passed a set of meters for the different motors [O] and then was distributed for single drive of the machines: Separators A and B, cream Pasteurizer C, pumps D, E, F, G, H, J, M, P, S, V and X, churning and kneading machine K, butter packing machine L, whey separator N, butter refrigerator Q, cheese refrigerator R and ventilator groups T and U. Source: Hasselbalch-Larsen 1937b, 415.

dairy agenda since the 1910s. For instance, it had been argued that mechanic transmission systems wasted a lot of power, that the steam engines worked very inefficiently, and that these demanded high maintenance efforts and costs. It was also mentioned that this matter was of substantial interest for rural utilities: In the same way that municipal utilities often could take up supply to the local flour factory and thereby improve their load, rural utilities nearly always had a butter factory in their supply area, which complemented the evening and winter lighting peaks with their power demand during the daytime and their power peak in summer, when the largest milk quantities were processed. High voltage production or transmission companies might even have many butter factories in their supply areas, while for village or parish utilities the local dairy might be the only industrial consumer available.[45]

Indeed, some butter factories did adopt electric drive in the 1910s. They purchased electricity for power, and maintained their steam boiler for the production of heat. An early example is the Fredericia dairy, which adopted all-electric drive after at a major rebuilding in 1914. Two years later, a representative of the factory expressed satisfaction with the general operation and the economic savings of power purchase.[46] During the First World War several other butter factories followed, particularly after coal prices had risen, but electricity prices not yet. In 1916, for instance, the Vesterbro dairy in Århus chose power supply from the municipal utility, which gave significant cost savings. And on Zealand, the large rural utility NVE supplied power to some butter factories already from its establishment just before the First World War. To improve the supply characteristics of the utility, this latter firm even made 'an effort to expand the consumer circle with butter factories', as its chief engineer and later director Holger Hasselbalch-Larsen put it in retrospect.[47]

Yet when also electricity prices started to rise quickly in 1917, the advantage of electricity purchase disappeared, and it was observed that 'as long as butter factories could employ their waste heat, electric drive can hardly be economically feasible.' Only in cases, where the steam consumption was low - for instance because the butter factory had a large cheese production - purchased electric power might cause cost savings.[48] And in 1920 Christian Jørgensen of the co-operative Tudse Næs dairy north of Holbæk argued that electric drive also might be feasible, if the dairy was situated close to the public power station, and electricity was very cheap: His dairy had adopted a single (eighteen kilowatts) electromotor to drive its line shaft in 1915, and recently conducted comparisons of the new system of purchased electric power and autoproduced heat with the old system of autoproduced mechanical power and heat for eight days each suggested that the new system was some twenty percent cheaper.[49]

In general, however, the argument of cheap co-production of heat and power was maintained and electrification avoided. For instance, Niels Sørensen of the co-operative Boulstrup dairy in Eastern Jutland reported that tests in his dairy had confirmed the theoretical argument. The Boulstrup area had been electrified in 1914 through a co-operative transmission company, of which Sørensen also was the chairman, and which received its electricity from the Odder utility, in which it was a co-owner. In 1920 the utility and the dairy agreed to compare the systems of steam and electric drive, alternately running each system for a week during half a year. But even though the Odder-based public electricity supply system was known as one of the cheapest in the country, and electricity was available to the dairy for merely ten øre/kWh, which was very low in post war prices, the expenses of autoproduced heat and purchased electric power were significantly higher than the coal expenses of autoproducing both heat and mechanical power. The utility thereafter dropped the idea of butter factory electrification, as in general electric drive would not be feasible in butter factories.[50] At the same time, the NVE utility on Zealand observed to its regret, that when the coal prices stabilized after the war and the butter factories increased their production capacity, the previously connected factories one by one returned to combined autoproduction of heat and mechanical power. Hereby they followed the recommendations of the dairy consultants, which generally recommended the decentral co-production of heat and power as the cheapest option.[51] And although the general concern for the electrification of agriculture also led for instance the Danish association of utilities to argue that dairy electrification was economically feasible (figure 11.2), electrified butter factories remained a rarity.

The plate pasteurizer and the early diffusion of electric single drive

As the large heat demand of butter factories seemed to obstruct the introduction of electric drive, already in the mid 1910s agitators for electric drive hoped that innovations in pasteurization technology would decrease the steam demand, and thereby make the technically superior option of electric drive also feasible economically. For instance, it was suggested that electric heating could replace steam heating, so that both light, power and heat should be purchased in the form of electricity.[52] And few years later the ongoing research at the University of Liverpool, where Frederick C. Livis treated milk with electricity under very high tension to kill microorganisms - up to three thousand volts to kill tuberculosis bacteria - was cited as a development which might make electric drive feasible.[53] However, these ideas were not developed into market technologies.

On the other hand, also steam heated pasteurizers were a field of research and efficiency improvements, which resulted in a reduced fuel consumption.[54] For instance, by 1910 so-called regenerative equipment became available, where the heat of the pasteurized skim-milk was used to pre-heat the cold cow milk before skimming. This reduced the heat demand and thereby the fuel demand considerably, and Danish butter factories massively adopted this technology during the First World War. But a break-through with decisive implications for the power situation only occurred with the development of the heat exchanger or 'plate-pasteurizer', as it was called in Denmark. Previous pasteurizers had consisted of closed steam chambers surrounding open milk chambers, in which the milk was circulated and heated. Plate pasteurizers, by contrast, consisted of a number of parallel steel sheets with some one millimetre's distance. Between the sheets, alternately milk and hot water were circulated in closed circuits and exchanged heat. Moreover, the plates could be connected in series, so that one machine contained different departments: As the skim-milk zig-zagged through the parallel plates, it first received heat from the steam in the pasteurization department, then gave heat to the cold cow milk in the preheating department, and finally gave the remaining heat to cooling water in the cooling department. In this plate system, the pasteurization speed and thereby capacity was greatly increased, while the lack of a steam chamber and effective heat exchange reduced the heat consumption to only a fourth of the previous.[55] The plate pasteurizer had been invented and produced in Great Britain in the early 1920s, and was produced by Danish manufacturers from 1929, starting with the Silkeborg machine factory. In the 1930s it was rapidly adopted by Danish butter factories, and like in other countries rapidly replaced open pasteurizers.[56]

As all observers agree, the replacement of the old 'three machine system' of a preheater, a skim-milk pasteurizer and a cream pasteurizer by the plate pasteurizer changed the heat and power economy of the butter factory drastically, and thereby also made electric drive feasible.[57] Due to the great reduction in steam consumption, the waste steam of the steam engine could no longer be fully employed, and the advantages of combined heat and power production decreased. Even worse, the introduction of plate pasteurizers increased the power demand of the butter factory substantially, because they used high-pressure pumps to circulate the milk at a pressure of about three atmospheres. Neither the steam from this increased power production could be employed in the production process. While dairy managers had expected that plate pasteurizers would reduce the fuel costs, instead the increased power demand might increase them.

If steam drive was replaced by electric drive, however, the fuel savings of the plate pasteurizer might indeed be exploited: A system of electric power supply combined with a smaller boiler for heat supply might now prove cheaper than maintained heat and power supply from the same system. As an alternative to all-electric drive, butter factories could use purchased electric power for some power intensive machines such as the compressor of the refrigerator and the pumps, and maintain steam drive only for the separator during the daily two hours of skimming. For this purpose, the small steam engine might be maintained, and much of the waste steam might be used to heat the water for the plate pasteurizer and other purposes.[58]

In the first half of the 1930s, a number of butter factories introduced a plate pasteurizer as well as electric single drive. However, instead of purchasing their electricity, they often preferred to autoproduce electricity. In 1931 a representative of the co-operative Funder butter factory near Silkeborg in Jutland claimed that this factory was the first to adopt electric drive from an autoproduction system. The reduced heat demand of the new plate pasteurizer was supplied by a separate high-pressure steam boiler, while power was provided by a diesel generator and electric single drive, which replaced the steam engine and the line shaft drive system. It was explicitly stated that it was the reduced steam consumption of the plate pasteurizer, that made diesel-electric drive cheaper than steam drive. In addition, the waste heat of the diesel engine was also used, not for pasteurization, but for other heating purposes.[59] In the same year, also the co-operative Randers butter factory adopted electric drive by autoproduced electricity, using the municipal utility as a back-up. Also here the system used electric single drive, the advantages being the reduction of power losses and the hygienic improvement of disposing of mechanical transmission systems.[60]

By the mid 1930s, also dairy consultants accepted the new option of electric drive. State consultant Niels Balle could, in collaboration with the private research institution Teknologisk Institut, present test results that underlined the significant fuel savings for diesel-electric drive, in particular if waste heat of the diesel engine was used for other heat purposes. In his view, the plate pasteurizer had finally challenged the heat and power supply system of Danish butter factories, which had been largely unchanged since the 1880s.[61]

To this dairy consultant Harald Jensen added that the most important precondition for electric drive was its reliability; yet as the massive introduction of electric drive in German butter factories from the late 1920s illustrated, modern casing made electric motors save to use also in damp dairy buildings.[62] Given this reliability, he underlined the qualitative advantages of electric drive in the butter factory, starting with the improved hygiene: It was now possible to dispose of the mechanic transmission systems, which previously had fostered and circulated bacteria and mould in the building. Second, electric transmission reduced maintenance and cleaning costs and made operation easier to survey. Third, it enabled a flexible design of the production process; for instance, the separators could be placed centrally in the skimming room instead of near the axle near the wall, and thereby could be reached from all sides. And the cooling machine with its large power demand had often been situated near the steam engine in the engine room, but could now be situated where cooling was needed. A fourth advantage was that expanding butter factories saved space, as the boiler room could be decreased and the engine room abolished. Notably also Jensen observed that about all butter factories, that had introduced electric individual drive in the past years, autoproduced their electricity, and used utilities for back-up or at most for supplementary drive. And indeed, neither experiences nor calculations suggested that even with low electricity prices, there would be large savings in case of electricity purchase.

Finally, explicitly addressing the issue of autoproduction versus purchase of power, State dairy consultant Johannes Jensen from Åbenrå in Southern Jutland doubted that butter factories would massively purchase electricity, even though the plate pasteurizer made electric utilities more competitive: Whereas previously electricity prices had to be as low as one øre per kilowatt-hour to make purchase attractive, he estimated that now a price of about six øre/kWh was competitive. Yet the reliability of supply remained an additional problem: Even for a technically advanced system as the large Southern Jutland supply system, this reliability was unsatisfactory. Jensen believed that butter factories would chose to autoproduce their electricity during the separation process, when also heat was needed for pasteurization, and at best purchase electricity from the utility the rest of the time, when waste heat could not be employed.[63] In 1937 he found this view confirmed by the dairy statistics for Southern Jutland, which showed that steam powered butter factories with plate pasteurizers still had the lowest fuel costs, followed by steam-electric butter factories, while electric butter factories supplied from electric utilities had rather high fuel expenses. Given the qualitative advantages of electric drive, he then recommended butter factories to autoproduce of electric power: Temporarily they might combine the autoproduction of steam power with purchase of additional electric drive, but in the long run steam-electric drive would be economically superior, while it also guaranteed the reliability of supply.[64]

Electricity purchase and the final electrification of the butter industry

From the second half of the 1930s, however, the electricity purchases of Danish butter factories increased rapidly as they massively adopted electric drive. They most often combined the purchase of electric power with the autoproduction of steam power during the skimming process: In the SEAS supply area, for instance, only three out of one hundred and six butter factories in the area had not been connected to the utility by 1940, and in the second half of the 1930s electricity sales to butter factories had increased almost by a factor three. Of these connected utilities, however, only six exclusively run on purchased power. The others combined electricity purchase with decentral steam power production: Twenty-four factories only purchased electric lighting, while the remaining majority of butter factories combined the purchase of electric power with autoproduction of steam power.[65] And a 1941 census by the association of Danish dairies showed that on a national scale, electric drive had been introduced in about half of the fifteen hundred butter factories; of these, nearly three-hundred had adopted all-electric drive, while more than four hundred had partial electric drive.[66]

Like in the case of the flour industry, the electric utilities played an active part in this transformation process. Already in 1936 dairy consultant Harald Jensen had observed that the success of electric drive not only followed changes in the power situation within the butter factories, that is, the introduction of the plate pasteurizer, but also changes outside the factories: Electric utilities increasingly offered butter factories advantageous supply conditions.[67] Jensen considered it a precondition for electricity purchase that reliability was guaranteed, for instance through ring connections in the transmission grids, and by situating the maintenance and repairs of power lines outside the opening hours of butter factories. In addition, the electricity prices should be very low, meaning that utilities had to recognize the advantage of butter factories as daytime electricity consumers. He reported that he had participated in several negotiations, which had resulted in supply conditions advantageous for both the butter factory and the utility, and hoped that this practice would spread.

The initiative on behalf of the electric utilities was taken by the above mentioned engineer Holger Hasselbalch-Larsen of the large NVE company, which participated in the East-Danish centralized system. Inspired by the developments in Germany, where the electric utilities had raised the issue of electricity supply to the butter industry and achieved it in close co-operation with dairy organisations, he suggested the same strategy in Denmark. To start with, he developed a close co-operation with dairy consultant Harald Jensen: They jointly went on a study tour to Germany, and presented their views on utility strategies to support butter factory electrification to the relevant rural production and transmission companies at a theme discussion at the association of large scale rural utilities DOFF [*Danske Oplandcentralers og Forsyningsselskabers Forening*] in 1936.[68] One year later, both also contributed to a special issue of the journal *Elektroteknikeren* on butter factory electrification. In this way, they placed the electrification of these factories upon the electric utility agenda.

Besides this general discussion, the NVE company and also the Southern Jutland utility showed the way by developing strategies to attract butter factories as customers. In the case of the NVE utility, the issue was raised in the early 1930s by a butter factory, which had recently bought a plate pasteurizer, and now informed on the conditions for electricity purchase. The utility responded by offering to install an electricity supply system free of charge for a test period. The system drove only the pumps, cooling machine and churns, and thereby reduced the fuel expenses of the steam engine. The butter factory was satisfied and bought the system, as its fuel expenses were significantly reduced.[69] It was this event that led Hasselbalch-Larsen to conclude that butter factory electrification again might be feasible, and in collaboration with dairy consultant Harald Jensen he negotiated new contracts with other butter factories. For instance, when the NVE company made a contract with the Gørlev butter factory in 1936, it guaranteed the butter factory the low costs of the scheme of heat autoproduction and power purchase. Also other butter factories were contracted in individual negotiations, often with participation of dairy consultant Harald Jensen to convince the butter factory boards (figure 11.3).[70]

In Southern Jutland, butter factories were situated in the supply areas of the various co-operative transmission companies, which received their power from the large Southern Jutland utility connected in the Northern Germany centralized system. Contrary to the North-Western Zealand case, these utilities attempted 'to get the butter factories connected originally against the recommendation of the regional state dairy consultant, Johannes Jensen. For as mentioned above, Johannes Jensen recommended butter factories to use steam-electric drive.[71] The utility strategy to still obtain butter factories as customers was on one hand to convince the single butter factory: Like the NVE company, the Southern Jutland transmission companies also financed and installed electric motors for a trial periods to pull the existing line shaft system. In almost all cases, this showed satisfactory reductions in the fuel expenses, and the butter factory decided to make the purchase a permanent arrangement. Notably, it was observed that the economic advantages of purchased electric power supply instead of autoproduced steam power supply varied directly with the introduction of the plate pasteurizer.

On the other hand, a general tariff policy should attract the butter factories as a group of consumers. For as butter factories only were small factories, the utilities were only interested in their load, if they connected to the electricity supply networks in large numbers. As also practised for other industries, director Jes Christiansen of the Southern Jutland utility recommended to set electricity prices for this category of consumers so low, that the attraction for electric purchase was large. By the mid 1930s, the transmission companies owning the Southern Jutland production company could offer electricity to small power consumers for some twenty øre per kilowatt-hour; yet butter factories would only pay some seven øre, which made electricity purchase attractive for most of them. As prices decreased during the 1930s, also dairy consultant Johannes Jensen changed his view: Pointing at the advantageous tariff policy of the utilities and the increased reliability of public electricity supply due to ring connections in the transmission networks, he now unambiguously recommended electric drive by purchased electricity.[72]

The strategies of these companies in turn accelerated the butter factory electrification process: In 1941 nearly eighty percent of all butter factories in Southern Jutland had introduced electric power. More than half had all-electric drive. And in the Holbæk county in the supply area of the NVE company, some seventy percent had been electrified. Although only thirty percent used all-electric drive, this was still twice the country average. In addition, also in the supply areas of the NESA and SEAS companies, which likewise promoted dairy electrification, the large majority of butter factories now used electric power.[73]

Finally, in the post war period the butter factories further increased their electricity purchases. During the war and even in the early 1950s it was observed that local conditions of electricity supply still varied the economic feasibility of electricity purchase for existing butter factories, but certainly all newly established butter factories would adopt all-electric drive.[74] The pricing issue was still mentioned as a factor, which could make steam drive or autoproduction of electricity feasible. This was particularly so in small co-operative societies, such as rural village utilities and transformer societies, where members might reject different electricity prices for different members. Therefore butter factory representatives were most pleased with the rationalization of the public electricity supply structure after the war, which implied that butter factories could connect to the transmission networks of large companies and often gain supply through their own transformer station against favourable prices.[75] With the success of centralized electricity supply and the following organisational rationalization on the countryside, therefore, the steam or diesel engines of the butter factories were ultimately replaced with electric motors powered by purchased electricity.

Autoproduction and purchase of electricity in the cement industry

A final case of interest is the cement industry. As described in chapters two and six, the cement industry differed from the flour and butter factory industries in its early adoption of autoproduction of electric drive. In 1936 the cement industry relied on electromotors nearly completely, and six out of seven cement factories autoproduced their electricity: No less than ninety-seven percent of the electric motor capacity was driven by autoproduced electricity. This situation had not changed by the late 1940s.[76] It was also described how autoproduction was particularly attractive in the cement industry due to the large size of electricity consumption, the high utilization time of the generating capacity, and possibly also the co-production of heat and power.

However, in the post war period the purchase of electricity was gradually increased, and as some cases may illustrate, also in the cement industry the negotiation with electric utilities could lead to a transition to electricity purchase. A first example is Aalborg Portland's factory Dania at the Mariager Fjord in the supply area of the Randers municipal utility.[77] The cement factory had already purchased additional electricity from the Randers utility, but after the War it faced a major expansion of its power station, and therefore was willing to negotiate on fully external power supply. The utility, in turn, had developed the practice of contracting large industrial customers at specially negotiated electricity prices since the First World War. In 1946 it managed also to contract the cement factory, which it considered as 'an immensely valuable customer, even though electricity of course had to be supplied at a very low price', as a utility representative put it in retrospect. The Randers municipal utility then constructed a sixty kilovolts transmission line directly from its power station to the factory. When the system became operational in 1949 and the factory had shut down its autoproduction plant, it consumed about a third of the electricity production of the Randers municipal utility.

Another illustrative case is that of the co-operative cement factory in Nørresundby. This factory not only autoproduced its electricity, but also supplied large amounts of surplus electricity to several public utilities in the Vendsyssel region. As the factory and the utilities agreed, it was the high utilization time of the generating capacity that made this arrangement so attractive. But in 1962 the factory did close down its autoproduction system and commenced electricity purchase. The context for this decision was on one hand a radical change in the public electricity supply situation. During the 1950s, the Ålborg municipal supply company had erected and thereafter expanded a new power station at the opposite (Southern) bank of the Limfjorden, which by 1960 had an engine power of hundred and eighteen megawatts, and had been integrated in the West-Danish power grid. Whereas the cement power plant earlier had been the largest in the region, it now was small compared to this new power plant. In addition, the NEFO partnership made electricity from this plant available in the Vendsyssel region on a power grid. As a result, the cement factory rapidly lost importance as supplier of electricity to the public: While it had supplied most of the electricity demand of the Vendsyssel region in the late 1940s, in 1960 only the public supply companies of Nørresundby and surroundings purchased approximately half of their electricity from the factory. The other half was purchased from NEFO and hence mainly produced at the large Ålborg power plant.

Under these circumstances, the co-operative factory reevaluated the feasibility of its autoproduction plant in the early 1960s: The relatively high operation and maintenance costs were problematised, and the fact that power production only was a secondary task to cement production was emphasised. On the other hand, the feasibility of the autoproduction plant decisively depended upon the electricity price set by the public supply company. As it was retrospectively described by a participant in the negotiations, these were very 'fierce' negotiations and ended with NEFO offering 'very favourable conditions' for electricity purchase. This tipped the scales in favour of public electricity supply.[78]

Finally, it was described in chapter six that Denmark's largest cement factory, Aalborg Portland's factory in Rørdal at the Southern bank of the Limfjorden in the supply area of the Ålborg municipal utility, maintained its autoproduction system until the early 1990s. Yet also in this case the importance of autoproduction was gradually reduced. As the autoproduction system had been written off, it remained economically feasible - particularly when the heat demand increased with the change from coal to fuel oil as a primary energy source of the factory. But after the Second World War, the economic advantage of autoproduction was no longer as self-evident as it had been previously, and did no longer provide incitements for new investment in this 'secondary' activity to cement production. Therefore, the factory maintained its existing autoproduction installation, but also extended its co-operation with the Ålborg municipal supply company to buy an increasing amount of additional electricity to meet the increasing electricity demand of the factory.

Notably, also in this case the public pricing system was a decisive factor, as was clearly revealed when the Rørdal factory finally shut down its power plant in 1992: A new and more beneficial pricing agreement with the Ålborg municipal supply company was mentioned as the immediate cause, which made full electricity purchase cheaper than maintaining the old autoproduction system, which by now had rather high maintenance costs.[79]

The cases of the flour, butter and cement industries were among the most surprising examples of the absorption of autoproducers in public electricity supply systems. In all cases, electric utilities played an active role in changing the feasibility of the different supply options by innovations in the pricing systems or by individual negotiation with the single factories. Also in the case of autoproduction systems, then, the ultimate success of large scale public electricity supply might be tied up not only with implicit technical and economical properties, but also with contingent events (such as specific technical changes in the production machinery of factories) and social innovations and interactions.

12
Conclusion:
The mechanisms of consolidation and scale increase

"What, people ask, is the interest of Danish energy policy? What consequence for the world at large is there to the choice made by a country of five million people?"[1] Such are the opening sentences of N. J. D. Lucas' (1978) study of Danish energy policy. His answer was that even though the Danish decisions did not affect the world markets for energy, the study of Denmark provided an instructive and attractive example of correspondence between institutional structure and energy policy, and 'the importance of a particular example is independent of size.' In a similar way, the history of electricity supply in Denmark may not have affected developments elsewhere very much - at least not until wind turbines recently became an important export article. Still, this dissertation hopes that the example of Denmark provides an instructive angle upon the development of electricity supply in modern society at large.

In the historiography of electricity supply, internationally as well as in Denmark, this development has usually been framed as a succession of electricity supply configurations of still larger scale. The historiography thus reflects what has been defined as progress in the field since the early twentieth century. In addition, the economic logic of this development is normally presupposed, and analyses of the mechanisms of change often take shape of refining the economic explanations of scale increase. Even constructivist studies, which since Thomas Hughes' (1983) important work have analysed the social context of the invention and consolidation of new, larger scale electricity supply systems, have followed the succession scheme and underlined its economic logic. They left the explicit assumption of the economic superiority of larger scale systems relative to their smaller scale predecessors unchallenged, and merely replaced a 'hard' economic determinism with a 'soft determinism' of economic factors in the direction of scale increase.

In this dissertation, the analysis of the development of electricity supply in Denmark is framed in a strategical opposition to such histories of scale increase. Instead of following the succession of still larger scale electricity supply systems, it follows four systems with a different scale of supply from 1920, when they had all been introduced, to 1970, when the largest scale system had ousted the others. It also avoids the presupposition of an ahistorical economical superiority of larger scale systems, to which 'social' or 'political' concerns might stand in opposition. Instead, the different systems are analysed symmetrically from the point of view of the actor groups engaged in electricity supply, which chose to maintain or to abandon them, and with focus upon their arguments for doing so. It thereby carries the constructivist project into a direct confrontation with the economic determinism of scale increase.

It is this strategy and its results, that may have interest, not for 'the world at large', but for the interpretation of the history of electricity supply as such - also in other countries than Denmark. This final chapter briefly recapitulates the results of the strategy, and concludes by extending the perspective of co-existing systems and actor groups to the electrification processes in some other countries in a brief and superficial glance.

The consolidation of decentral systems and the economics of electricity supply

A first, descriptive result of the framework of co-existing electricity supply systems and the actor group perspective concerns the history of decentral supply systems. The largest scale configuration of electricity supply, that of centralized supply, dominated contemporary discussions as well as the historiography of electricity supply in Denmark from its successful introduction in the late 1910s. But decentral systems did not disappear, not even gradually. Instead they were maintained and often expanded, so that by the eve of the Second World War they not only constituted the large majority of electricity supply systems, but also produced most of the electricity in terms of output - and a considerable part (thirty percent) by 1950. Decentral electricity supply systems had a specific dynamic and development, which should not be reduced to merely 'remains' of old technologies in the shadow of the success of centralized electricity supply. At least for the case of Denmark, there is something to describe.

A second result, perhaps of larger analytical interest, concerns the economic feasibility of smaller and larger scale systems. It has been observed in other cases from the history of technology, that the presupposed technical superiority of newer technologies compared to their predecessors was a retrospective construction (or distortion), which had no validity in the contemporary society under study. Thereby the explanation of technical change in terms of technical progress proved tautological. In a similar way, the actor group perspective allows for an examination of attributions of economic superiority and inferiority to the different electricity supply systems in contemporary society.

In this respect, the Danish case shows that there has not always been a consensus on the economical superiority of larger scale electricity supply systems. Certainly, members of the actor group of 'large utilities', which had a stake in large scale supply, had argued for such superiority from the beginning of the century. And at an early stage this group came to dominate the debates on electricity supply in technical societies and in government circles. Notably, a study of the choices and motives of other actor groups, which had a stake in decentral electricity supply, shows that also these judged the different electricity supply options in terms of economy: All actor groups thus agreed that economic concerns should guide their decisions, perhaps constrained only by the technical demand of reliable supply. But contrary to the judgement of the actor group of large utilities, the representatives and members of these other actor groups claimed the economical superiority of their decentral electricity supply systems at least until the 1950s. The diffusion of centralized systems as well as the consolidation of decentral systems was justified in terms of an economic superiority.

Let me sum up the different economic arguments, which came up in the empirical research. To start with, centralized supply was from the beginning justified ideologically by an improvement of national economy, for which a decentral electricity supply structure was considered at best unfortunate and at worst disastrous. There were three arguments for such an economical improvement. First, the concentration of production in large power plants entailed important economies of scale. With regard to investment costs, large production units costed less than small production units per kilowatt capacity. And with regard to running costs, large power station used less personnel due to a concentration of operation and maintenance efforts, and less fuel due to more efficient, large scale machinery per unit of electricity produced. Second, there were large savings on investments in back-up capacity, as such back-up could be shared by different power stations through the power grid. And third, there was a possibility of exchanging surplus energy on the power grid: It was possible to distribute a given electricity consumption or load at a given moment over the available production units in the system in such a way, that the production units in operation were fully used. In addition, it was also possible to exploit an 'economic mix' of different energy sources in one system, for instance by using cheap hydropower whenever it was available, and by using thermal power plants if not.

Historians of electricity supply have taken over these arguments, which are now well-known. But thereby they heard only the claims of the dominant actor group, not those of the other actor groups, which were less visible in contemporary discussions. Therefore, perhaps, the consolidation of decentral systems by these groups is often explained not in economical, but in social categories such as stubbornness or local patriotism. But the actor group of medium-sized and smaller urban municipalities and their utilities lined up several arguments for the economic superiority of decentral electricity production in the single town. This included indeed rather small towns, certainly in an international perspective. On one hand, they questioned the economic competitiveness of centralized supply in Denmark as such. In want of large, concentrated natural energy resources such as large waterfalls or coal mines, large industrial centres and a high electricity consumption per inhabitant, Denmark lacked the factors that made centralized electricity supply economically attractive abroad. In addition, the high costs of establishing a power grid might outweigh possible economic advantages of a concentration of production. Besides, in such a large transport system there would also be large power losses, while the risk of breakdowns in the long transmission networks decreased the reliability of supply. The economic advantages of centralized electricity supply were therefore rather uncertain: And in the light of this uncertainty, it would not be economically rational to make the huge investments that it required. Hence the suggestion, that propagators of centralized supply should conduct the experiment with their own money, not the tax payers'. Finally, the economy of decentral town systems could be further improved, for instance by establishing a combined heat and power production to gain an extra income from heat sales. This would not be possible if electricity was purchased elsewhere. Also, the interconnection of decentral municipal power stations might be judged as an economic benefit, for instance in saving on back-up capacity.

And on the other hand, this actor group pointed at several economic factors specific to the municipality, which made decentral electricity production even more attractive. This included the municipal concern to use the electricity supply business as a source of income: Decentral electricity production entailed a full control with the price of electricity, but the purchase of electricity from a larger utility might entail that the latter employed market principles once it had a monopoly, increasing its prices, and thereby reducing the profit margins of the receiving municipality. Moreover, local production also meant local income for town citizens, both directly in employment at the power station, and indirectly through the demand for construction work, material and fuel transport, and service in general.

The actor group of rural, mainly co-operatively owned utilities put forward similar arguments for the consolidation of decentral rural systems. Spokesmen and members of this actor group claimed that even very small local systems in villages or small towns often remained economically feasible. Also here it was argued that such local systems were more reliable, and that the large investments in high voltage lines outweighed the possible economic advantages of a concentration of production. In addition, also this actor group claimed a number of special advantages. For instance, if they produced and distributed direct current, they could use accumulators, so that the production machinery only had to run (and consume fuel) part of the day, while accumulators could take over supply in low consumption periods. Another advantage followed the power sources: First wind energy was developed as a comparatively cheap energy source for small systems, later such systems would massively be equipped with efficient diesel engines that were particularly cheap in operation, when oil prices were low. In addition, some actors exploited Western Denmark's modest but cheap hydropower resources, while others ran systems on small islands, where the purchase option required expensive submarine cables. Finally, for actors running local systems a transition to supply with purchased alternating current electricity from a larger scale system was particularly expensive, as it demanded the rebuilding of the distribution system and of many consumer appliances. As it were the consumers that took the decisions at general assemblies of the rural co-operatives, this factor had to be included in the calculations.

Finally, also the many different actor groups running autoproduction systems argued that autoproduction of electricity could be cheaper than purchase from a larger scale system. These groups too emphasised the reliability of autoproduced electricity, which was not only a technical factor, but a major economic factor in many industries. In addition, industries with a steady power demand could boast of a much higher utilization time (or load factor) of their generating capacity than public utilities, so that they repaid their machinery sooner, and thus had lower fixed costs of electricity production. Other actor groups might have different arguments for the cheap autoproduction of electricity: If an engine was already available, and if the electricity demand was small, a generator could be connected for electricity production; this might hardly increase the fuel expenses, and reduced the investment costs, as an engine already existed. Also if the electricity demand was small but the distance to a public transmission network large, as for many farms, small and cheap autoproduction units might be feasible. In other cases, the demand for large amounts of heat in the production process made combined heat and power production possible, which primarily resulted in low running costs of electricity production.

The focus upon different actor groups in the study of the development of electricity supply, at least in the case of Denmark, teaches that central as well as decentral supply systems could be justified with reference to their superior economy. Notably, the accept of this situation by propagators of centralized supply (for example in the case of large industrial autoproducers) or would-be objective observers (such as the Electricity Council) suggests that these justifications often were reasonable; particularly before the Second World War, these generally agreed that the consolidation of decentral systems was economically rational. Most surprising perhaps, this includes the large number of small village systems. It seems therefore that an explanation, which claims economical superiority of larger scale systems, indeed is guided by assumptions that have no validity in the historical context.

Closure mechanisms

If the economical explanation of scale increase cannot stand alone, the actor group perspective does allow for inclusion of the social processes within and among different actor groups as an important variable in the development process. The question then is not how the different systems in fact related to each other economically, but how the actors behind the systems anticipated the possibilities of their supply systems in a changing technical and economical context, not in the least affected by historical contingencies. Under the circumstances of one time, some actor groups might find that decentral supply systems were economically and technically superior; and under the different circumstances of another time, they might find centralized supply superior. In this view, economic superiority is not a property of one supply system relative to another, but a construction itself, which demands an examination.

The construction of the economic superiority of decentral systems as well as centralized systems occurred from the beginning, when the different actor groups engaged in these systems with economic motives. Once these systems had been established, the economic considerations summarized above applied. In addition, by following the different actor groups the study was able to observe the subsequent social process of constructing a consensus among the different groups upon the economic superiority of centralized electricity supply. The economic feasibility of the different supply options was redefined in the terms, that the actor group of large utilities had advocated from the beginning of the century. Thereafter the definition or closure process was forgotten, and new generations - and sometimes also the old ones - identified economic superiority as an intrinsic property of large scale supply. Also the mechanisms of this closure process deserve a brief recapitulation.

First, it is important to notice that the new consensus built on several developments, which were external to the different electricity supply configurations, and in this respect can be characterized as historical contingencies. Such a precondition was the availability of a power grid of interconnections and also connections between most actors on the supply field, which followed the contingency of the Second World War. Thus, the West-Danish power grid and many connections of smaller systems to larger ones were not built to achieve economical advantages, but to maintain electricity supply in the first place, when decentral systems run out of fuel. This event changed the economic comparison of decentral and centralized systems to the advantage of the latter, as its large investment costs of (inter)connections disappeared - the investments had largely been made. Another precondition was the rapid increase of electricity demand in the post war period, which was intertwined with the rise of the modern energy-intensive consumer society. This gave a competitive advantage to centralized supply systems, as local systems had difficulties to supply the increasing amount of electricity on their low capacity distribution networks. Finally, the massive adoption of alternating current in the electrical world outside direct current systems resulted in more, better and cheaper availability of alternating current consumer appliances, which also made it increasingly difficult to maintain local systems with direct current supply.

Second, there were a number of social mechanisms, which gave centralized supply an economical advantage that it might not have had before. For instance, it took the social innovation of municipal co-ownership of the centralized system to draw the actor group of municipalities into the centralized supply option. In this arrangement, they owned the means of production and therefore were guaranteed electricity in large units at cost price, while they could maintain a decentral pricing policy and still make a profit on supply to the benefit of the municipal treasury. This arrangement also involved larger rural transmission companies, and in turn made electricity from the centralized system available cheaper at the countryside, and thereby decreased the feasibility of decentral rural systems.

Another social innovation was that of pricing. The larger electric utilities gradually adopted the practice to set their electricity prices so low, that it would be attractive for decentral producers to quit decentral production and purchase electricity instead. This mechanism was first formulated as an effective strategy to lure autoproducers into purchase of electricity: Autoproducers were convinced by electricity prices much lower than those of other consumers, while for the utility there would still be the advantage of an increasing turnover and also an improved utilization time of the generating capacity, which made it economically possible to decrease prices. Often, such prices would be determined in individual negotiations, taking the price of autoproduced electricity as a point of departure.

But the mechanism of pricing not only proved crucial for the decline of autoproduction. Often, large utilities provided substantial economic support to smaller utilities to make the option of purchase from the centralized system attractive. This support could take the form of low prices, but also of participation in the high investment costs of changing to supply from the centralized system. In addition, the consumers which owned decentral systems on the countryside could often enter the large co-operative transmission company, which now took over supply, without paying the usual entrance fee. Thereby they gained co-ownership of a valuable, capital intensive system for free. Such agreements of course changed the 'objective' economic assessments, as those made by the Electricity Council, decisively to the advantage of centralized supply. Historical contingencies and social innovations and interactions, therefore, were integrated elements of the ultimate success of centralized electricity supply in Denmark.

An international perspective

In the case of Denmark, the study of the history of electricity supply in a framework of co-existing systems thus showed that also decentral systems had a continued dynamics worth of description, while the accompanying actor group perspective showed that the later success of centralized supply was not an economic necessity, but presupposed historical contingencies and social innovations and interactions. But how far do these results apply in general? In particular, the study of Denmark alone cannot 'prove' that contingencies and social factors played a *decisive* role in the final success of the configuration of electricity supply. Did the Second World War, the energy-intensive consumer society, the innovation of co-ownership and the economic support to the dismantling of decentral systems only speed up a process, that would have occurred under all circumstances?

This last assumption, which would also save the presupposition of the technical and economic rationality of the process of scale increase, seems a very strong one. This is so primarily because the phenomenon of scale increase in electricity supply seems to have occurred in parallel in many industrialized countries, regardless of their different preconditions. If the process of scale increase was not only a national, but a transnational success, must there not be a larger rationality than the contingency of history or social interactions? This dissertation therefore ends with a brief address - not a study - of the developments in electricity supply in some other countries from a perspective of co-existing systems and actor groups, which suggests that the assumption of the economic superiority of centralized supply is much weaker than it seems to be at a first glance.

First, it would be preliminary to conclude that centralization occurred as smooth in other countries, as it is often taken to. Like the historiography of electricity supply in Denmark proved biased towards scale increase, also the international historiography might have neglected the consolidation of decentral systems, starting with the leading countries in electrification Germany and the United States. These two countries are known in the historiography of electricity supply for their invention of large scale production technologies, as well as their rapid introduction of still larger scale configurations of electricity supply: According to Hughes (1983), they had developed centralized supply to a stage of maturity by 1930.[2] To my knowledge, the consolidation of decentral systems during this development in these countries has not been studied. But there are some figures that suggest such a consolidation. For instance, in 1941 there were still some two thousand power stations for public supply in Germany. And in 1947, there were nearly twice as many (thirty-eight hundred) in the United States.[3] Relative to population, these numbers were lower than in

Denmark: Against Denmark's some four hundred systems, in Germany and the United States there were between one hundred and two hundred public power stations per four million inhabitants. But as a completed system of centralized supply in Denmark would include merely ten to fifteen power stations, one may conclude that even in these leading countries there was a large majority of decentral electricity supply systems still in the 1940s. The consolidation of these decentral systems is interesting, even though they might be linked up in larger networks and purchased additional electricity. In addition to these public supply systems, there was also a large number of autoproducers in both countries: It has been observed, for instance, that industrial autoproduction in the United States revived in the 1930s, and the statistics of the European Community show that autoproducers in Germany accounted for some forty percent of the electricity production still by 1960.[4]

A similar argument may apply to other countries as well. For instance, in 1970 autoproducers accounted for fifteen percent of the total electricity production in the Netherlands, nineteen percent in France, twenty-four percent in Italy, thirty-one percent in Belgium and fifty-seven percent in Luxembourg.[5] With regard to autoproduction, then, Denmark in fact stands out as a country, where centralized supply was particularly successful.

In addition, it is worthwhile to point out that in some countries centralized supply was not a huge success at all. To take a very different example from Denmark: When the Danish state after the Second Word War decided to establish a public electricity supply system on Greenland (a colony until 1953, and thereafter a full part of the Kingdom of Denmark), it chose the electricity supply configuration of diesel-powered local systems to supply the single towns - starting with the capital Godthåb (Nuuk), the system of which was operational in 1949. Later these systems might be expanded with means for high voltage transmission and become district systems, but they did not interconnect. In this large and scarcely populated country, centralized supply did not have an economical attraction at all: The number of state-run town systems (from 1987 under the Greenland Parliament *Hjemmestyret*) had increased to sixteen by the early 1990s. And by 1980, there were also about thirty municipally or co-operatively owned village systems, besides a number of autoproducers.[6]

Another example is that of Norway. Whereas Greenland was characterized by a very low electricity consumption, Norway had and has the highest per capita electricity consumption in the world - about twice as high as that of the United States.[7] This relates in part to the availability of cheap hydropower, which is accessible in small amounts locally, as well as in large amounts in particular places. But despite the scale advantages of large power plants to exploit the large hydro-power sites, several actor groups in Norway such as municipalities, co-operatives and autoproducers continued to produce their electricity decentrally. This was so even after the State Power Board NVE (later *Statkraft*) and others started to exploit such very large hydropower plants, and by the 1980s had integrated them in a national power grid. By 1990 large scale and small scale power plants continued to co-exist, and about two-thirds of the electricity consumed by the general public was produced locally, and not transported over the national grid.[8]

The success of centralized supply thus is less universal than it seems to be. Moreover, a second objection to the assumption of its implicit economical superiority is that also in countries, where large scale electricity supply proved a huge success, this involved the choices of different actor groups: These often actively manipulated the conditions of supply to the advantage of scale increase, and did not let market mechanisms determine, which electricity supply configuration was economically superior. Richard Hirsh (1989) has described several decisive social mechanisms for the United States, where privately owned utilities and electrotechnical manufacturing industries - two groups that largely lacked in Denmark - created a consensus upon scale increase, which worked as a strategy for expansion until technological boundaries were reached in the 1960s. Notably, Hirsh speaks of a 'unique political and social process' where entrepreneurs defined the 'fundamental parameters and core elements' of the American utility industry:[9] By the mid 1930s, utility managers had developed a 'grow and build strategy' as their main business management principle, which meant that they continuously pushed for a scale increase to make electricity available cheaper for still larger sections of the population. Hirsh emphasises that the grow and build strategy was not necessarily economically rational from a supply point of view: As utility managers were engineers and no financial experts, they uncritically adopted a culture of technical progress, and their fascination for large scale technology might be "distracting them from purely economic considerations."[10]

Furthermore, this strategy was made possible by several social innovations, including promotional pricing, which also proved important in Denmark. Other innovations were the strategies of large, privately owned utilities to seek an agreement with the State governments, in which they offered the governments regulatory oversight of their business in return for a monopoly position. Hence the State governments were drawn into the consensus of scale increase, combining a concern for cheap access to electricity for its population with a concern to assure the utilities a fair return on investment to make this possible. In this way, a situation of 'legalized monopoly control' was created, which gave large private utilities the competitive advantage to small, municipal utilities. A third social innovation, finally, was that of the holding company buying a large number of utilities. Such holding companies not only could offer a safe investment because they spread their risks over many utilities, but also pool financial, managerial and technical resources. And it were these holding companies, which often organized interconnections between the different systems and thus worked for scale increase. In 1924, only twenty holding companies controlled sixty-one percent of the public production capacity in the United States.

Finally, the grow and build strategy depended upon a small group of manufacturers - primarily General Electric and Westinghouse - which dominated the market, and produced still larger scale generating equipment. The electrotechnical manufacturers thereby also formed a social group important for the consensus on the direction of electricity supply developments. Moreover, particularly in the early years they had a direct interest as an actor group, because they owned many of the utilities. Thus, by working for scale increase through their utilities, they could create an expanding market for their own production of equipment.

In several European countries, by contrast, government bodies would often intervene in the electricity supply business as actors, and thereby distort the economical balance to the advantage of a scale increase in electricity supply. In Great Britain and in Sweden, for instance, the national governments used legislative and economic power to create a centralized system. In Great Britain, as already mentioned in chapter five, the central government decided after the First World War to impose a centralized organisation on the electricity supply industry, and few years later the Central Electricity Board was established to build and operate the national grid. The Board also selected the power stations, which were allowed to supply electricity to it. And when the electricity supply business was nationalized after the Second World War, also the generation of electricity was taken over by the State.[11] In Sweden large power companies, the State Power Board Vattenfall in particular, first exploited the huge but concentrated hydropower resources by establishing large district systems. Later, the State Power Board financed and ran the national power grid. Also in this case, smaller producers were not allowed to use it.[12] In both cases, centralized supply was a success, but not without massive support from economically and politically strong actors.

Finally, such engagement of politically powerful actors might also occur on a lower political level. In the Netherlands, provincial authorities engaged in the public electricity supply business from the 1910s to ensure electricity supply to the rural areas, thereby stimulating rural enterprise and countering the urbanisation process. In most of the country, the provinces used the power of the provincial decree to gain control of the business, whereafter urban municipalities or other actor groups could not establish new decentral systems or expand old ones. The result was impressive: Slightly smaller than Denmark in area and two times as large in terms of inhabitants, by the eve of the Second World War there remained only thirty-four producing utilities. Relative to population, this is much less than in Denmark, Germany or the United States at this time. Yet neither this notable success of large scale supply did result from an undisturbed economic rationality, but from the engagement of an actor group with social concerns and political power.[13]

As these brief examples suggest, the assumption of an unambiguous economic superiority of large scale electricity supply stands less strong than it seems to. In this perspective, the Danish case studied in this dissertation even represents a comparatively free development: In the absence of economically or legislatively very strong actors, such as large private enterprise, large electrotechnical manufacturers, and national or provincial governments, the actor groups that did engage in electricity supply could decide themselves which supply option to chose. Also in this respect, the development of electricity supply in Denmark seems interesting in an international perspective.

Summary

The aim of the dissertation is to (re)describe and (re)interpret the development of electricity supply in Denmark, which had resulted in a giant technical structure that covered the country by 1970. In the existing international and Danish historiography, this development is normally described as a succession of electricity supply configurations (or systems) of still larger scale. In addition, the process of scale increase is normally explained in terms of the economic superiority of larger scale systems relative to their smaller scale predecessors, and the historical discourse often takes shape of demonstrating or refining the economic principles in play. Notably, also 'constructivist' work, which has placed the invention of larger scale systems in a perspective of social mechanisms and historical contingencies, maintains the succession format and assumes that once invented, larger scale systems had the economic advantage to their smaller scale predecessors. A hard economic determinism is replaced by a 'soft' one.

This dissertation aims to carry the constructivist project further into a direct confrontation with such economical determinism. Leaning on Wiebe Bijker's *The Social Construction of Technology* (1990), it does not follow the succession of still larger scale supply systems, but instead follows four systems with different scales of supply from 1920, when they had all been introduced, to 1970, when the largest scale system had ousted the others. This reveals that decentral systems had a history also after larger scale successors were introduced. Moreover, the dissertation takes the point of view of the 'actor groups', who chose to maintain or abolish the different systems, as its focus of examination. In this way it avoids to copy uncritically the discourse of the dominant group, which claimed the economic superiority of large scale supply from the very beginning, and can scrutinize the validity of this claim for the historical case.

The investigation consists of three parts. Part I describes the development abroad and the introduction and diffusion in Denmark of each of the four electricity supply systems: Autoproduction systems supplying single sites or buildings; local systems supplying the public within a few kilometres distance; district systems supplying the public within a radius of perhaps thirty kilometres or more; and centralized systems, which in time would cover entire Denmark by two systems only. Of particular importance was the diffusion process, which determined the importance of each system in society. This diffusion was tied up with the engagement in electricity production and supply of several actor groups with relatively homogeneous concerns: Autoproduction systems spread with the engagement of a large number of actor groups, such as different branches of industry and the group of farmers, which were attracted by the economic or qualitative advantages of the new energy source. Local

systems spread with the engagement of the two actor groups of urban municipalities and rural consumer associations. The former ran the new service to obtain a new source of income for the municipal treasury. The latter sought to improve the competitiveness of agriculture and rural handicraft, industry and trade, and did not want to wait for electrification to come from the towns. District systems were spread by the same two actor groups: Municipalities expanded their local systems to district systems to concentrate production, supply large industries or extend supply to the rural hinterland of their towns. Rural consumer associations founded district systems to spread the advantages of electrification to entire rural districts. Finally, the diffusion of centralized systems followed the engagement of a small actor group of the largest utilities in Denmark, which sought a further expansion and to obtain economies of scale and other advantages of this supply form. From the late 1910s, this actor group and its arguments dominated technical societies and government circles.

Part II investigates the motives of the different actor groups to consolidate decentral systems despite the successful diffusion and proclaimed economic rationality of centralized supply. The framework of co-existing systems reveals that still by 1950, these decentral systems made up the large majority of supply systems in Denmark, and produced more than half of all electricity. In addition, the actor group perspective shows that the different groups maintaining decentral systems also had economical concerns as their main criterion of judging the different electricity supply options. But they claimed the economical superiority of decentral systems. First, the large costs of and power losses in the power lines of larger scale systems might outweigh the advantages of a concentration of production. And second, decentral production might be cheaper due to specific circumstances: Autoproducers might have a more steady load than public utilities and could therefore exploit their machinery better; autoproducers and municipal utilities might decentrally co-produce heat and power; municipalities also wanted control with prices to ensure their profits, and were concerned with local employment; and small rural utilities used accumulators to replace fuel-consuming engines part of the day, cheap wind-electric systems, diesel engines or hydropower. In addition, these groups agreed that decentral production had a larger reliability of supply. Notably, at least until the 1950s these claims of the economical feasibility of decentral systems were often confirmed by representatives of large utilities, who failed to attract them as customers, and in particular by the Electricity Council, a state institution making economical assessments of the different supply options. Thus there is no evidence for an intrinsically economical superiority of centralized supply, which can explain its success.

Part III analyses the final success of centralized supply from the perspective of the different actor groups. It shows that a consensus was constructed within and among the different actor groups on the economic superiority of centralized supply, which since has been projected back in time. But this consensus presupposed several historical contingencies (events external to the intrinsic performance of the single supply system) as well as social mechanisms, which made centralized supply more attractive than it would have been otherwise. Such historical contingencies include the Second World War, which motivated small actors to participate in the construction of power lines to keep up supply as they ran out of fuel; the emergence of a post war, electricity-intensive consumer society, which caused larger electricity demands than the low capacity distribution networks of local systems could carry; and the choice of alternating current supply in the 'outside' electrical world, resulting in more, better and cheaper consumer appliances for this type of current and the growing dissatisfaction of consumers with small scale direct current systems. The social mechanisms include the invention of co-ownership of the centralized system, which was a precondition for municipalities to give up decentral production, because it enabled them to combine the economic advantages of large scale supply with those of decentral pricing. Another social innovation was the strategy of larger utilities to use pricing, individual negotiation, and considerable financial support to make electricity purchase more attractive for small actors than to continue decentral production. In this sense, the economic superiority of centralized supply was a combined social and technical construction.

Finally, the concluding chapter briefly and superficially confronts these results, which show that in Denmark decentral systems had a history after the introduction of their larger scale successors, and that the intrinsic economic superiority of large scale supply is a retrospective construction, with the international developments. These seem to support the presupposition of a larger, economic rationality, as centralized supply seems a transnational success regardless of the different preconditions in the different countries. However, a reading of selected secondary sources with a focus on decentral systems shows that centralized supply was not as universal a success as it often is taken to be. And a focus upon the strategies of actor groups shows that if centralized supply became a success, this was not a purely economically rational development following undisturbed market forces; instead, it normally involved the active manipulation of the economic comparison between small and large scale systems to the advantages of the latter by economically or legislatively strong actor groups. The strategy applied in this dissertation, therefore, seems feasible and corrective of an existing bias in the historiography of electricity supply.

NOTES

Notes to the Introduction

1.E.g. Kaijser 1997.

2.Valéry is cited in Bloch 1954, 66. See also Hughes 1983, 5 and Nye 1990, ix.

3.For Denmark, see Kristensen & Olsen 1981, Rasmussen 1982 and Wistoft et. al. 1991- 1992. For the comparison see Kaijser 1995. Examples of recent studies of other countries include Coopersmith 1992 (Russia), Lévy-Leboyer 1988 (France), Hesselmans 1993 and forthcoming (the Netherlands) and Myllyntaus 1991a, 1991b (Finland). See also the more heterogeneous collections of conference papers in Cardot (ed.) 1987 and Trédé (ed.) 1990, which for instance include regional or national studies of electricity supply in such different countries as Italy, Spain, Japan and Algeria.

4.Hughes 1983, 462-465.

5.The following reading primarily uses Jarvis 1958, Bowers 1978 and Hughes 1983, which account for the technology in great detail. The same four-stage model is uncritically adopted as a point of departure in external histories such as Landes 1969, 285-286.

6.See for instance the Organisation for European Economic Co-operation 1956, 91 and the Statistical Bureau o the European Communities 1966, XIII. The latter acknowledges, however, that the precise definition of autoproducers may vary from country to country.

7.In formula form, the ratio of the transport power loss [$P_{loss}=I^2 * R$] and the transported power [$P_{transport} = V * I$] increases linear with the transported power as well as the resistance of the wire, but decreases quadratic with the transport voltage [$P_{loss}/P_{transport}= (P_{tranport}*R)/V^2$]. I= electric current in Ampère, V= transport voltage in Volt, R= resistance in Ohm.

8.Jarvis 1958, 200. Concerned with the 'logic' of technological progress, Jarvis does not observe that the Deptford scheme in fact was a commercial failure. See for instance Byatt (1979), 103.

9.Hughes (1983) calls such systems for 'universal systems', defined slightly different by the combination of high voltage, alternating current transmission and low voltage, alternating current as well as direct current distribution. He reserves the term 'regional systems' for the supply form with different power stations interconnected in a grid. However, in Dutch and Swedish studies of electricity supply, the term 'regional systems' is used for single power stations using high voltage transmission, that is, Hughes' universal systems, see e.g. Kaijser 1995. This study therefore avoids these terms.

10.Faaborg-Andersen 1942.

11.For a brief biography see *Dansk civilingeniørstat* ... (1956), 150 (nr. 1476).

12.The three wire system was already patented by John Hopkinson in England in 1882, and was used for electricity transport from the power station to central points near the consumers. From these points, two wire systems supplied the single consumers with a voltage they could use: Lighting consumers were supplied by an outer (+220 volts or -220 volts) and the middle wire (0 volts)and thus received 220 volts for their incandescent lamps, while power consumers were supplied by two outer wires and received 440 volts for their electric motor Balancing generators kept the average electricity flow in the middle wire of the three-wire system at zero, so tha the electricity transport between power station and consumer points was carried by the outer wires at an effectiv transport voltage of 440 volts, thus increasing the economical supply distance relative to a transport voltage of 220 volts. Five-wire systems were also introduced to further improve the distribution distance, for instance in Paris in 1889 and Manchester in 1893, but it was generally agreed that the increasing difficulty of regulating the electricity flows in the wires outweighed the advantages of a larger supply area. Jarvis 1958b, 228-229.

13.Faaborg-Andersen 1942, 42.

14.Faaborg-Andersen 1942, 46, 51 and 58.

15.Faaborg-Andersen 1943, 51.

16.Henriksen 1939, 368.

17.Faaborg-Andersen 1942, 57-58; Elektricitetsrådet 1957, 54; Bak 1961, 72-76.

18.Böcher 1945, 31.

19.Kristensen & Olsen 1981, 5.

20.*Ibid.*, 40-49.

21.*Ibid.*, 55-69.

22.Rasmussen 1982, 8-10.

23.Rasmussen 1982, 176-178.

24.A promising part, for instance, is pp. 203-211. For the complaint on a lacking analysis see also Henry Nielsen's (1992) review. For a survey of the work see Wistoft 1994.

25.Kaijser 1995, 34. Likewise, in describing the success of centralized supply - originally inspired by the economic mix of thermal and (partly imported) hydropower supply - it assumes that by the late 1920s, "the benefits of integration had become obvious" (p. 46), so that the Danes now decided to also interconnect large thermal plants in lack of hydropower. In this formulation, the process of scale increase seems to demand only a psychological process of recognizing the economic advantages, which in themselves are beyond doubt.

26.Jones 1959, 24.

27.Staudenmaier 1985, 145-146.

28.This aspect is highlighted in Lintsen et.al. (eds.) 1992-1995. See also van der Vleuten 1994b.

29.Bijker 1990, Ch. 1 and Pinch & Bijker 1984.

30.One may object that Hughes' (1983, 1987) popular system theory enables the inclusion of decentral production systems in the analysis, and that it allows for a symmetrical analysis. Because Hughes' work, besides a very important analysis of the phenomenon of technological systems, is authoritative and seems obligatory for all later further work on the field of electricity supply systems, this deserves a further comment.
Indeed, it is true that decentral power producers can be included in the analysis of an expanding technological system to the extent, that such producers are connected in the grid, and thereby become part of the expanding network. For instance, Hughes includes autoproduction systems in the large scale (regional) systems of RWE in Germany and Newcastle area in England. Yet this is not the same as structurally including industrial plants in the analysis, as plants that remain in complete isolation from the grid are apriori excluded. And as this dissertation will show, at least in Denmark there were plenty such autoproducers still by 1970.
With regard to the issue of symmetry, it is also true that Hughes locally uses such symmetry, for instance in his analysis of the competition between direct current and alternating current technology, known as the battle of systems, in the 1890s. But these are not Hughes' categories of succession: The point in the analysis of the battle of systems is that the alternating current system is a solution to a problem (the transport distance problem) within the 'local system', and the resolution of this conflict between the two current systems produced the larger scale system of 'universal system' (which equals the 'district system' in this study), which absorbed both direct current and alternating current technology. It is this latter system, that according to Hughes has the decisive economic advantage (due to load management) compared to the 'local system' which it succeeds. A truly symmetrical study should therefore analyse local systems (dc), alternating current systems (ac) and universal systems (ac-dc) in similar terms, as Todd (1987) explicitly did in his comparison of electrification in three cities in the German Ruhr area.
Finally, Hughes' famous comparison of electricity supply in London, Berlin and Chicago before the First World War underlines the asymmetry of explanation: In Berlin and Chicago the 'universal system' was succesfully introduced thanks to its superior economy, and absent or co-operative politicians allowed this. In London, this supposedly superior system originally failed, which is explained with reference to a political system supporting local supply. My point, it should be noted, is not to deny the accuracy of this observation, but to make explicit the scope of analysis within a perspective of growing systems.

31.Hjulström 1940, 283.

32.Sources: 1910: Elektricitetsrådet 1957, 38. 1923-1970: The annual electricity supply statistics, see Danmarks Statistik 1923-1952; Det Statistiske Departement 1962; and *Dansk Elværksstatistik* ... (1973).
Demarcation criteria: Autoproduction systems are mentioned separately in the statistics. Public supply systems: 1923-1950: Local systems include all rural village utilities [*Jævnstrømscentraler i landdistrikterne*], and urban utilities [*Bycentraler*], which did not produce alternating current (with alternating current generators or convertors). District systems include all urban utilities [*Bycentraler*], which produced alternating current with alternating current generators or with convertors, and all rural district utilities [*Oplandcentraler*] - unless these are characterized as centralized systems. Decentral (local and district) systems are defined as such only, if they have a more than incidental power production - in practice larger than a tenth of their electricity purchase. This criterion excludes power stations merely used as peak load or back-up systems. Centralized systems, finally, include those utilities which exploited 'very large power stations' in 'interconnection' with other very large power stations. 'Very large power stations' are those, which represented the largest class of power stations capacities in Denmark at a given time. 'Interconnections' are power lines that directly connect two primary power stations, and have a large transport capacity in the order of magnitude of that of single production units. Possible net imports are also included under centralized supply.
1960, 1970: Local systems include all 'secondary utilities' [*sekundære værker*], which exclusively produce low voltage electricity (direct or alternating current), and all very small 'B-utilities' [*B-værker*], with the exception of those, for which it is known from elsewhere that they produced high voltage, alternating current (primarily according to the electricity supply statistics of 1950). District systems include 'secondary utilities' producing high voltage, alternating current; 'B-utilities', which are known from elsewhere to produce high voltage, alternating current; and 'primary utilities' [*primære værker*], which were not interconnected (such as the large system on the island of Bornholm), or which were much smaller in terms of capacity or output than other primary utilities and included in the grid only because of special circumstances (such as the CHP plant in Randers and the smallest CHP plant *Gothersgade Elektricitetsværk* in Copenhagen).

33.As table 1.1.

34.For this concept see Bijker 1990a, 52-58.

35.Bijker 1990a, 92-97.

36.Barsøe Sørensen 1953, 265.

37.The development of primary engines, generators, wires etc. is described in the international literature. For wind power in Denmark see e.g. Karnøe 1991 and Thorndal 1996. For atomic power in Denmark see Flemming Petersen 1996 and Henry Nielsen et. al. 1998.

38.For a survey see Buhl 1995.

39.Compare Hirsh 1989, 41 and Hughes 1983, figure X.11 to Vinding & Frydlund 1915.

Notes to Chapter 2

1.The following survey is primarily based on Jarvis 1958a and 1958b. For a newer and detailed account see also Bowers 1982. For an old but detailed Danish account see Prytz 1884.

2.Bowers 1982, 90-91 and Ch. 16.

3.These figures are cited from *Engineering* in "Elektrisk Belysning", *Industriforeningens Tidsskrift* Vol. 4 (1888), 94.

4."Elektromagnetisk maskine", *Industri-Tidenden* 2.r, 10.b (1874), 153.

5.Olsen 1878a, b.

6.Tychsen 1878/79, 160 ff.

7.For mention of some early systems see Rode (1942), 16-17 and Wistoft et. al. 1991, 13-16.

8.*Berlingske politiske og avertissements-Tidende*, August 22 and 27, 1857.

9.Olsen 1878a, 63.

10.Rode 1942, 19-20 and "Den danske dynamo-elektriske maskine", *Illustreret Tidende* Vol. 23 (1881-82), nr. 1165: 210-212.

11.According to Lütken 1883, 646.

12.N. C. Hansen 1886. The B&W and naval dockyard systems are mentioned in Rode 1942, 19-20.

13.N. C. Hansen 1886.

14. *Elektricitetskommissionen-Elektricitetsrådet ...* (1957): 38 and Danmarks Statistik, "Elektricitetsværker i Danmark 1931/32", *Statistiske Meddelelser (S.M.)* 4, 93, 5: 76.

15.Such sources of error include the exclusion of a number of systems, the capacities of which were not registered; the possibility of double registration; the uncertainty of a large number (128) of autoproduction systems, which were registered without mention of their field of production and therefore remain uncategorized in this table; and inclusion of few factories with a combined activety (such as combined machine factories and iron foundries) under the one category only.

16.See the 1923/24 electricity supply statistics in Danmarks Statistik 1925, 58. Prior to the 1931/32 electricity supply statistics, smaller autoproduction systems (often with a capacity of about one kilowatt) were systematically excluded. In that year, some five hundred systems were included that previously had been excluded. Danmarks Statistik 1933, 76.

17.E.g. Danmarks Statistik 1947, 80.

18.See the electricity supply statistics of 1933/34. Danmarks Statistik 1923-1952, S.M. 4, 97, 5, 80-81.

19.Juul 1884/85.

20.Zarthmann 1887-88, 36 ff.

21.*Ibid.*

22."Driftsomkostninger ved det elektriske lys", *Industriforeningens Tidsskrift* Vol. 5 (1889), 166-171 (following the *Zeitschrift des Vereins deutscher Ingenieure*).

23.E.g. "Forplantning af arbejde ved hjælp af elektricitet", *Industriforeningens tidsskrift* Vol. 4 (1888), 232-234 and "Brugen af elektriske motorer og deres fremtidsudsigter", *Ibid.* Vol. 8 (1892), 129-134.

24.For a clear survey see Devine 1983.

25.See e.g. Andresen 1913/14 and 1915.

26."Fabriksdrift", *Elektroteknisk tidsskrift* Vol. 13 (1909), 71.

27."Fabriksdrift", *Elektroteknisk tidsskrift* Vol. 13 (1909), 71 and "Elektriciteten i fabrikerne", *Elektroteknisk tidsskrift* Vol. 21 (1917), 43.

28.E.g. C. Stau Andresen 1913/14, 200.

29.For the following see primarily Bjørn 1982. For technical innovations see also van der Vleuten 1994a.

30.For a summary of the current state of historical reseach see Bjørn 1994.

31.Drejer 1925-33, 359; Bjørn 1982, 121; Danmarks Statistik 1899, table 7A.

32.*Ibid.* and van der Vleuten 1994.

33.See van der Vleuten 1994a for a comparison with the Dutch butter industry.

34.Hauberg 1889a and 1889b.

35.For dairy legislation see Bøggild 1910, 907-908; for a general background see Hyldtoft 1996, 239-244; and for a technical survey see Engberg 1925.

36.Niels Anton Hansen 1893; Appel 1895; "Elektricitetens anvendelse i mejerierne", *Elektroteknisk tidsskrift* Vol. 3 (1899), 50-51.

37.E.g. Birk 1901.

38. La Cour 1899.

39.Knudsen 1899.

40.Representatives of the branch included Niels Anton Hansen (1900) and Bernhard Bøggild (1900), while representatives of individual dairies included Andersen (1899) and Knudsen (1899, 1900).

41.Martens 1899, 841-843.

42.*Ibid.* and Niels Anton Hansen 1900.

43.Birk 1901 and Niels Pedersen 1901.

44.Erik Nielsen 1900.

45.A. M. Andersen 1899 and Martens 1899.

46.Christensen 1902.

47.Knudsen 1899, 1900.

48.Rasmussen 1902.

49."Forsøg med lysanlæg i mejerier. Forsøgslaboratoriets 54. beretning", *Mælkeritidende* Vol. 16 (1903), 261-265.

50.Agge 1902; Martens 1903. Moreover, dairies simply used the two wire system. Examples are the electric lighting systems of the Tryggelev dairy in 1909 (1.6 kW, 65 V), the Bodilskær dairy in 1909 (1.62 kW, 65 V), the Fjordsminde dairy in 1914 (1.5 kW, 65 V) and the Longelse Fuglsbølle dairy in 1914 (2 kW, 65 V). National Archives, Elektricitetsrådet, Journalsager nr. 718/09, 343/14, 247/14 and 377/19.

51.See primarily Nilsson & Larsen 1989, 167-188. For histories of the technologies involved see also Hamilton 1958, 483-487 and Holst 1923-26, Vol. IV, 50-58.

52.For the factory structure see f.eks. "Cementindustrien Før og Nu", *Cementindustrien* (1917), Vol. 9: pp. 54-57. For a detailed technical layout of the leading Danish cement factory see Drachmann 1915, 22 ff. and p. 93 ff. During the period of time under consideraton in this study, the basic layout of the factory hardly changed, even though grinder and kiln technology was gradually improved. Important machinery developed by the Danish F. L. Smidth company in the first half of the century included Unidan grinders, which combined ball and tube grinders (for crushing and grinding) in one design, and Unax rotary kilns, which combined kiln and cooling cylinders, see Jensen 1957.

53.Danish cement factories employed in average 732 hp. in 1906 and 1414 hp. in 1914. Shipyards employed 633 resp. 733 hp. in average, cotton mills 417 resp. 708 hp. and paper factories 318 resp. 654 hp. Finally, ice factories employed 764 hp. in average in 1914. *Statistisk Tabelværk* 5, A, 12: Table 29.

54."Elektriciteten i Cementfabrikkerne", *Elektroteknisk Tidsskrift* (1913/14), Vol. 18: pp. 93-95. This situation had not changed in the 1960s, see Witt 1966, 101.

55.N. C. Hansen 1886,. 324-325 and "Elektrisk Belysning paa Cementfabrikken Cimbria ved Hobro", *Den Tekniske Forenings Tidsskrift* Vol. 10 (1886-7), 149-150.

56.Drachmann 1915, 27-31 and 93 and 1923, 41.

57.E.g. "Elektrisk Drift i en Portlandcementfabrik", *Elektroteknisk Tidsskrift* (1909), Vol. 13: p. 93 and "Elektriciteten i en Cementfabrik", *Elektroteknisk Tidsskrift* (1912/13), Vol. 17: p. 45.

58.For the following see primarily "Elektriciteten i Cementfabrikkerne", *Elektroteknisk Tidsskrift* (1913/14), Vol. 18: pp. 93-95.

59.Drachmann 1924, 35-47.

60."Elektrisk Materialetransport i Cementfabrikker og Teglværker", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 27-28 and 42 on p. 27 and Drachmann 1915, 80-81.

61.Capacities of the autoproduction systems of the seven Danish cement factories by 1910: At the Mariager Fjord: The Cimbria factory: 14,2 kW; the Dania factory: 75 kW; the Kongsdal factory: 78 kW. At the Limfjorden: The Nørresundby factory: 80 kW; the Norden factory: 562 kW; the Danmark factory: 830 kW; and the Rørdal factory: 1130 kW. Source: National Archives, Electricitetsrådet, *Registre over anmeldelder* .....

62.For the historical background of this development see van der Vleuten 1994b.

63.Cit. from "Elektricitet og Mølledrift", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 127-130 and 138-139 on p. 127. The 1906 industrial census noted no electric motors in the flour industry at all, and the 1914 census only a few. In addition, the registered autoproduction installations (some of which the censuses might have missed) in 1910 remained typically very small with very few exceptions. Of these, the largest electricity producer (Munke Mølle in Odense) only reported that electricity was used for lighting, while two others (factories in Vejle and Esbjerg) did use electric drive on a very limited scale only. *National archives*, Elektricitetsrådet, Registre over Anmeldelser 1908-1933. For the individual flour factories see *Ibid.*, Journalsager nr.333/40 (A/S Valsemøllen Esbjerg) and nr. 629/50 (A/S Munke Mølle, Odense) and *Illustreret Tidende* (1915-16), Vol. 57: nr. 39 (Vejle).

64.See the series of articles "Antændelse af melstøv", *Möllen* Vol. 13 (1898-99), 44 ff., taken from the German journal *Die Mühle*.

65.Schiödt 1887/88 and Haase 1890/91/92.

66."Det elektriske Belysningsanlæg på Dampmöllen ved Langebro", *Tidsskrift for Skandinavisk Mölleindustri* (1987/88): pp. 121-123.

67.See Koefoed & Hauberg's announcement in the milling journal *Möllen*, Vol. 12 (1897), nr. 310.

68.E.g. *Möllen* Vol. 17 (1903), 150, 168, 172, 174-174.

69."Lydum mølle", *Tidsskrift for vindelektrisitet* 1904/5, 23-26.

70.Lütken 1883, 646 and Hauberg 1891/92.

71."Elektriciteten i Bryggerierne", *Elektroteknisk Tidsskrift* Vol. 14 (1909/10), 145.

72.*Ibid.* 145-147 andVol. 15 (1911), 1-2, 16 and 123-124.

73."De forenede bryggerier", *Elektroteknisk Tidsskrift* Vol. 20 (1916), 33.

74.For a survey see primarily Larsen 1994, Johansen 1988, 72-75, 114-115, 168-170, 235-236 and 300-301; Jørgensen 1964; and *Den danske Papirindustri. De forenede Papirfabrikkers* ... (1914). Good descriptions of machinery are Haylock 1978 and Holst 1925, Vol. III, 388-402.

75.E.g. "Udnyttelse af Vandkraft til elektrisk Drivkraft", *Nordisk Papir-Tidende* (1895), Vol. 1: 35; *Nordisk Papir Tidende* (1898), Vol. 4: 42.

76."Elektrisk Drift i Papirfabrikker", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 12-13 and 23-25.

77.Finally, other advantages of individual electric drive included substantially improved lighting conditions and worker safety (partly because the potentially dangerous belts were disposed off, partly because the machine could be turned off instantly by pressing a button placed anywhere in the factory in case of accidents). Andresen 1928, 71-72 and 75-76.

78.National Archives, Elektricitetsrådet (archive nr. 1404), "Registre over anmeldelser 1908-33": B 149, 150 and 151 (covering the periods 1907-1915, 1916-1922 and 1923-1933 respectively).

79.Mogensen 1942b, E8.

80."'Der Papierfabrikant' om Ravnholm Papirfabrik", *Dansk Papir Tidende* (1907/1908), Vol. 3: nr. 5.

81.In other paper factories with partial electric drive, the factory workshop might use electric power, while the paper making department still used mechanical power transmission. E.g. "Elektrisk Drift i Papirfabrikker..", p. 12.

82.O. Røs-Petersen, "Elektrisk Drift i Papirmaskiner", *Ingeniøren* (1934), Vol. 43: II 29-31.

Notes to Chapter 3

1.The following is based on Hughes 1983, 31-46 and Friedel, Israel and Finn 1987. For a survey in Danish see Nielsen et. al. 1990, 168-176.

2.Edison quoted from the *New York Sun* (September 16) in Friedel et. al. 1987, 13.

3.Edison quoted from the *New York Sun* (October 20) in Hughes 1983, 32.

4.Hughes 1983, 21ff. and 34 ff.

5.Hughes 1983, 30 and 39 ff.

6.Byatt 1979, 15-18 and Bowers 1982, 135-141. See also Dunsheath 1962, 141 ff.

7.The Edison system in Rotterdam of 1883 is usually not mentioned in historical surveys, as its existance was only recently discovered. Besides, like the Holborn Viaduct system in London it was running only for a few years, see e.g. Hesselmans 1993. For Berlin see Hughes 1983, 72-73; For Sweden see Hjulström 1940, 283-284 (eng. summary) and Rode 1942, 32.

8.Byatt ..., ...By 1903, all British towns larger than 100.000 inhabitants had public electricity suppy.

9."Statistik der Elektricitätswerke in Deutschland .... "(1905), 63 (table 5).

10.For instance, Hyldtoft mentions the electricity supply system of a bakery in Lyngby North of Copenhagen, which besides the bakery also supplied street lighting on a contract with the municipality from 1888. Hyldtoft 1993, 53-54.

11.According to Wistoft et. al. 1991, 24, which quotes from *Illustreret Tidende* 1881, nr. 1148.

12.Tychsen 1878/79, 153.

13.Tychsen 1881/2, 167.

14.Juul 1884/85, 158.

15.See chairman Hoskiær's comment in Juul 1884/85, 162.

16.Zahrtmann 1887/88, 29-43.

17."Elektrisk lys", *Den Tekniske Forenings Tidsskrift* Vol. 13 (1889/90), 126-127.

18.Wistoft et. al. 1991, 38.

19.The first discussions on public electricity supply in Copenhagen in the 1880s are described in detail in Rode 1942, 22-30. For Stillmann's proposed system see the map opposite p. 24.

20.See Rode 1942, 16-30.

21.Director of the light service Howitz cited in Rode 1942, 24-25.

22.For the Berlin concession agreement see Hughes 1983, 185.

23.Rode 1942, 32-34.

24.For a survey see Wistoft et. al. 1991, 37-49, on which the following is primarily based.

25.See Rode 1942, 43-45 and Wistoft et. al. 1991, 43-44.

26.Rode 1942, 30 ff.

27.See Wistoft et. al. 1991, 45.

28.For the preparations and the general technology of the first Copenhagen power station see Rode 1942, 39-42 and 46-52 respectively. For specific information on the power station and the distribution system see pp.112 ff. and 186 ff. Windfeld-Hansen's arguments for direct current in his 1889 report are referred in Wistoft et. al. 1991, 44.

29.Rode 1942, 54-56 and 57-61.

30.Different systems exploited by one actor (in the case of Copenhagen light service) are counted as one. For 1897 see Danmarks Statistik 1899, table 7 (nr. 182). For 1905 the statistics of production list 38 local systems in the provinces and eight local systems in the capital area, and included seven block stations, see Danmarks Statistik 1910, pp. 27-31. In addition, a survey by the Industrial Society lists local 36 systems in the provinces, see Lindberg & Mackeprang 1907, 182- 886. For 1910 (238 systems) see Vinding 1913, tables I and II (from which I exclude six systems using district supply technology). For 1915 (389 systems) see Vinding and

Frydlund 1915, tables I and II (from which, again, district systems are excluded). Finally, for 1923/24 (429 systems) see the electricity supply statistics of 1923/24, tables I and IV. Of 73 local systems in towns I have excluded those in Hadsund and Løgumkloster as they purchased all or nearly all of their energy.

31.Lindberg & Mackeprang 1907, 183 and 185 includes the ownership forms of the province systems. For the systems in the capital see Danmarks Statistik 1910, 28, which also includes a fifth and very small municipal system in Frederiksberg (probably combined heat and power production from a new incinerator plant).

32.An extreme example is the village of Herning (which in fact gained town rights in 1912), which had grown from a village of some 240 inhabitants in 1870 to nearly four thousand inhabitants by the turn of the century and seven thousand inhabitants by 1910. By contrast, still in the mid 1920s some ten market towns had less than two thousand inhabitants. More typical were small towns like Haslev on Zealand or Vejen in Jutland, which in half a century expanded from 'normal villages' to so-called 'station towns', containing for instance municipal primary schools, secondary schools, doctors and pharmacies (and in the former case a hospital), banks, infant homes and a considerable business community with trading and industrial firms. By 1916 these small towns counted 3700 and 2600 inhabitants respectively, and were thus larger than a number of small market towns.
In practice, this administrative status is used as a leading demarcation criterion between town and village systems in the early listings of electricity supply systems compiled by the industrial society - and to some degree those of the electrotechnical society. See for instance Lindberg 1911, 224-231, including these towns as village systems, and Vinding 1911, arbitrarily including Herning, Haslev and for instance Fakse (1050 inh.) as town systems and towns like Vamdrup and Vejen (both 2000 inh.) as village systems. From the 1920s, the electricity supply statistics published by the Danish statistical bureau operate with a demarcation criterion defining towns as urban settlements with more than a thousand inhabitants. Village systems are thus defined as systems in settlements with less than a thousand inhabitants or lacking an 'urban' character.
This demarcation, however, again deviates from the current demarcation, defining a town as a settlement with two-hundred inhabitants or more, provided that the distance between the houses is less than two-hundred meters (unless this distance is due to public works etc.). With this definition, there currently are 1380 towns in Denmark (1992). Hans Christian Johansen, "By" in *Den store danske Encyklopædi* Vol. 3, 504-506.

33.The figures include a few block stations mentioned in the available statistics as public supply undertakings. Sources: 1906: Lindberg & Mackeprang 1907, 183 and Danmarks Statistik 1910, 28. The former lists 36 provincial local systems, which are not categorized. Fifteen of these were situated in urban municipalities and another five in urban settlements with more than 1000 inhabitants in 1901 (those in Hammel, Haslev, Skjern, Vamdrup and Vejen. See the *Salmonsens Konversationsleksikon*, 2nd edition 1915-28). The others were situated at the countryside. The latter source adds seven town systems within the capital. 1910: Lindberg 1911, 224-231 (tables A, B and C). After subtraction of seven district systems, Lindberg's lists contains 41 local systems in urban municipalities and 190 elsewhere. From the latter category, I have included 13 systems as town systems (situated in the following urban settlements with more than 1000 inhabitants: Bramming, Faxe, Hadsten, Hadsund, Hammel, Haslev, Herning, Kjellerup, Odder, Skjern, Søllerød, Vamdrup, Vejen. See e.g. Vinding 1911 and 1913). 1915: Vinding and Frydlund 1915, tables IA and IIA. After subtracion of 12 district systems these include 54 local systems in towns and 335 elsewhere. Of these town systems, I have excluded 1 system (Gudhjem) as a village system, while I have added 12 systems listed as village systems (situated in the following settlements with more than 1000 inhabitants: Bandholm, Gedser, Hadsten, Hadsund, Hammel, Helsinge, Høng, Kjellerup, Søllerød, Vamdrup, Vejen and Vester Brønderslev). 1923: Electricity supply statistics of 1923/24, including 73 local systems in towns (defined as urban settlements with more than 1000 inhabitants) and 358 in villages. Of the town systems, I have excluded two (in Hadsund and Løgumkloster) as they almost completely purchased their energy from elsewhere and therefor do not qualify as independent decentral systems.

34.Calculated on the basis of Vinding and Frydlund 1915, tables IA and IIA and the electricity supply statistics of 1923/24. For the demarcation of towns and villages, see the footnote above..

35.Book-keeper Galschiøt cited in Skaarup 1959, 10.

36.For a survey of the emerging electrotechnical industry in Denmark see Buhl 1995.

37.*Vejle kommunale elektricitetsværk* ... (1934), 9-16.

38.For Slagelse see Skaarup 1959, 9; for Odense and Ålborg see above; and for Frederikshavn see Thostrup 1947, 7-11.

39.In Nykøbing on Falster, the member of the municipal council 'elected to carry through the electrification case' was barrister Graae, who described the events in Graae & Bützow 1932, 20 ff.

40.According to many jubilee publications of municipal utilities.

41.For Randers see Westergaard 1931, 5-10; for Fåborg see H. J. C. Hansen 1957, 5-7; for Nykøbing on Mors see Andersen 1985, 17-21; and for Rudkøbing see Langhorn & Külsgaard 1945, 5-8.

42.For Slagelse see Skaarup 1959, 10-11; for Vejle see *Vejle kommunale elektricitetsværk* ... (1934), 9-16; for Odense see Wistoft et. al. 1991, 39; and for Frederikshavn see Thostrup 1947, 9.

43.For Odense see Wistoft et. al. 1991, 40-41; for Slagelse see Jacobsen & Hallenberg 1934, 17 ff.; and for Vejle see *Vejle kommunale elektricitetsværk* ...(1934), 17 ff.

44.Hyldtoft 1994, 97.

45.For this construction process see for instance Jørgensen 1985, 312 ff. and 331 ff. and Christensen 1991. See also *Købstadforeningens tidsskrift* Vol. 8 (1897), 22-28.

46.The degree of municipal independence can be exemplified with the relative high municipal income through municipal taxes, which were among the highest in Europe around the turn of our century; after Norway (65%), Danish municipal taxes made up some 60% of the Danish state taxes compared to some 51-54% in England, Sweden and Preussia, less than 40% in France and Italy and less than 20% in Austria and Russia For the figures see a review of V. Falbe Hansen, *Kommunernes financielle forhold* (Copenhagen, 1896) in *Købstadforeningens tidsskrift* Vol. 8 (1897), 22-28.

47.Hyldtoft 1994, 65 and 1995, 89.

48.Rausgaard 1991, 252-252; "Hvilke byer har vandværk", *Danmarks kommunale efterretninger* 1906/07, 163-164; and "300 landsby-vandværker", *Ibid.* 199-200.

49.See for instance *Købstadforeningens tidsskrift* Vol. 14 (1903), 160-165, which was an extended review of a book on the issue(T. H. Aschehoug, *Socialøkonomik. En videnskabelig fremstilling af det menneskelige samfunds økonomiske virksomhed. Vol. 1*, Kristiania, 1903).

50.Windfeld-Hansen 1898, 133-139.

51.*Ibid.*, 139-144.

52.*Ibid.*, 144-147.

53.Lunde-Nielssen 1906/07.

54.The request for electricity by the State Railways started municipal discussion in for instance Silkeborg and Struer, see Gislinge 1961, 1-10 and Vendelbjerg 1987, 8-9 respectively.

55.E.g. Wistoft et. al. 1991, 117-119. For a short biography see e.g. *Dansk civilingeniørstatistik* 1946 (nr. 781).

56.Westergaard 1931, 5-15.

57.*Ibid.*, p. 16.

58.Vinding 1913, 42-43.

59.Graae & Bützow 1932, 5-19.

60.Vinding 1913, 42-43.

61.Based upon accounts in a large number of available jubilee publications, which describe the decision process.

62.Jensen et. al. 1931, 5-7.

63.For Silkeborg see Gislinge 1961, 1-10.

64.For Slagelse, see Jacobsen & Hallenberg 1934, 16-24. For Vejle, see *Vejle kommunale elektricitetsværk* ... (1934), 17-36. For Frederikshavn see Thostrup 1947, 12-15.

65.Of the eighty market towns in 1924, only Hasle, Præstø, Storehedinge, Ebeltoft, Skanderborg and Rudkøbing did not have a power station according to the electricity supply statistics.

66.For the accumulated budgets of Danish market towns in 1918-19 see *Salmonsens konversationsleksikon* (2nd edition, 1915-1928), Vol. 15, 142-143.

67.Rager 1936b.

68.For Kerteminde see *Kerteminde kommunale elektricitetsværk* ... (1936), 4-8. For Odder see Israelsen 1931, 7.

69.Wistoft et. al. 1991, 119.

70.C. M. Hansen 1931, 6-12.

71.C. M. Hansen 1931, 31-32.

72.*Ibid.*

73.Castenschiold, Tvermoes & Dencker 1894.

74.Important journals were the *Tidsskrift for landøkonomi*, the *Ugeskrift for Landmænd* and the *Andelsbladet.*

75."Elektricitet ctr. hest og havre", *Ugeskrift for landmænd* 7. r., vol. 10 (1896), 506; G. Lorenz, "Zimmermanns elektriske plov", *Ugeskrift for landmænd* 8. r., vol. 1 (1897), 32-35; "Elektrisk kraft i landbruget", *Handelstidende* (appendix to *Ugeskrift for Landmænd*) (1898) CLXXX.

76."En billig drivkraft for landmanden. En erstatning for kul", *Ugeskrift for landmænd* 8. r. vol 5 (1901), 325-326.

77.Birk 1902. An extract was published in *Ugeskrift for Landmænd* 8. r., vol 6 (1902), 34-36.

78.La Cour 1906.

79.Hansen 1985, 179-297.See also Hansen 1994.

80.Thomas 1987, 50 ff.

81.Hansen 1985, 298-331.

82.Hansen 1985, 321 ff. and la Cour 1903, 98-99.

83.La Cour cited from *Tidsskrift for industri* (1906), 212 in Hansen 1985, 351.

84.See for instance la Cour 1903, part IV.

85.La Cour 1903, 108-109.

86.La Cour 1903, 104.

87.La Cour & Bjerre 1907, 10-17.

88.E.g. "Oversigt over Dansk Vindelektrisitets Selskabs virksomhed 1904-1912", *Tidsskrift for Vindelektrisitet* (1913), 587-591.

89.La Cour 1905-06, 184.

90.Hansen 1985, 330-344.

91.For listings see "Repræsentantmødet for D.V.E.S. i Askov den 29. oktober 1908", *Tidsskrift for Vindelektrisitet* (1908), 459-463 and "Oversigt over Dansk Vindelektrisitets Selskabs virksomhed 1904-1912", *Tidsskrift for Vindelektrisitet* (1913), 587-591.

92.Hansen 1985, 328.

93.Of those systems registered in the industrial statistic of 1906. Lindberg and Mackeprang 1907, 183.

94.The sample is taken from brief histories (often jubilee publications) of rural utilities published in the joint newsletter *Elektriciteten* of the associations of rural utilities in 1938 and 1939.

95.For a brief history of these rural utilities see "Hasmark-Egense elektricitetsværk", *Elektriciteten* vol. 1 (1938), nr. 9: 5-6; "Kappel elektricitetsværk", *Elektriciteten* vol. 1 (1938), nr. 10: 6; and "Elektricitetsværket 'Thor' i Hjerm", *Elektriciteten* vol. 2 (1939), nr. 6: 14-16. For the size of their supply areas in 1921 see Danmarks Statistik 1923, table VII.

96.For a brief history of these village utilities see "Hals elektricitetsværk", *Elektriciteten* vol. 1 (1938), nr. 10: 6; "Arden elektricitetsværk", *Elektriciteten* vol. 1 (1938), nr. 11: 8; "Ølgod andels-elektricitetsværk", *Elektriciteten* vol. 1 (1938), nr. 1: 7-11; "Tørring elektricitetsværk", *Elektriciteten* vol. 2 (1939), nr. 4: 3-5; and "Ulfborg elektricitetsværk", *Elektriciteten* vol. 2 (1939), nr. 5: 5-6. For the size of their supply areas in 1921 see Danmarks Statistik 1923, table VII.

97.See also Wistoft et. al. 1991, 157-159.

98.The statutes of the Tørring electric utility are reprinted in la Cour & Bjerre 1907, 38-41.

99.Bjerre 1909.

100.Bjerre & Bentsen 1911.

101.The installation costs of three thousand DKK. exclude electromotors. Bentsen 1909.

102.Vinding 1913, 52-61.

103.Pedersen 1908, 415 ff.

104.Vinding 1913, 52-61 (nr. 80).

105.Following the demarcation of the electricity supply statistics, in 1923 some seventy 'town systems' produced nineteen gigawatthours of electricity, while nearly three hundred sixty 'village systems' produced fouteen gigawatthours of electricity. As the former group also includes a number of small town utilities which regarded themselves as rural utilities, the output of both groups was probably in the same order of magnitude.

Notes to Chapter 4

1.For the international development of district supply see Hughes 1983, 79-174, on which the following is based.

2.Gaulard and Gibbs cited in Hughes 1983, 91 (from *Engineering* Vol. 35 (1883), 205).

3.A transformer consists of a pair of coils, where alternating current in the primary coil induces an alternating current in the secondary coil. A different number of windings in the primary and secondary coils produces a proportionally different size of the voltages (and, conversely, the currents). While already Gaulard and Gibbs' early systems used a high voltage transmission circuit to economically supply a number of low voltage secondary circuits, there has been disagreement in how far these systems indeed used the step-down function of transformers to produce low voltage for consumption. For as the latter were connected in series they could produce a low voltage over the individual transformers on the primary circuit, and Bowers (1982, 145-146) suspects that they merely used a 1:1 transformation ration to produce low voltage on the secondary circuit. Yet Hughes (1983, 89) calls this for 'a 'misunderstanding' and suggests that the step-down transformers were used both to step down the voltage and to vary it according to the preferences of the individual consumer. In any way, from the mid 1880s the transformers were connected on the primary circuit in parallel, and had a clear step-down function in transforming high transmission voltage into a low consumption voltage.

4.Hughes 1983, 96 and 105.

5.Hughes 1984, 121 ff.

6.Bowers 1982, 144-150.

7.Hughes 1983, 129 ff. and 135 ff.

8.Hughes 1983, 262-284. Hughes includes a list of the 55 large transmission systems (pp. 282-283, figure X.11).

9.See Steenberg 1903, 158-161.

10.Steenberg 1904, 159.

11.Steenberg 1904, 161. For a survey of the following course of events see Aubeck 1940, 207 ff.

12.Meyer's verdict is reprinted in Aubeck 1940, 208.

13."Betænkning afgivet af den af Ministeriet for offentlige arbejder under 24. oktober 1904 nedsatte kmmission vedrørende elektriske stærkstrømsanlæg"... 1906, 3611-3614. See also Meyer 1906.

14.See also the presentation of the Bill to Parliament by Minister Svend Høgsbro, stating the aim of 'providing electric power to the extent, that nowadays is wished for in wide circles in our country'; this demanded legislation to facilitate transport of power from the side of production to the site of consumption without more or less rational opposition from the owners of the land, which the electricity must pass. *Rigsdagstidende* Vol. 59 (1906-1907), Folketingets Forhandlinger, 6815. For the Act see "Lov om elektriske stærkstrømsanlæg" ... 1907.

15.*Rigsdagstidende* Vol. 59 (1906-07), Landstingets Forhandlinger, 1417.

16."Betænkning afgiver af den af Ministeriet for offentlige arbejder under 24. oktober 1904 nedsatte kommission ...", 3614.

17."Betænkning afgiver af den af Ministeriet for offentlige arbejder under 24. oktober 1904 nedsatte kommission ...", 3619-3622 and Meyer 1906, 140. For a history of the legislation on electricians see Rager 1940.

18.For a recent survey of early electrotechnical education see Buhl 1995. For a detailed account of the developments concerning the Polytechnical School see Lundbye 1929.

19.Harnow 1995, 172.

20.Cited from Lundbye 1929, 262.

21.For their biographies see Jespersen 1928, 611 (nr. 99) and 623 (nr. 164).

22.Rung 1928, 492.

23.Larsen 1904, 10.

24.Ulrich 1904-05, 117.

25.According to Nyboe 1907, 86.

26.See Ellert 1938, 7ff.; *Sydøstsjællands elektricitets aktieselskab* ... (1937), 3ff.; and Therkildsen 1996, 13 ff.

27.*Ibid.*

28.*Salmonsens konversationsleksikon* (2nd edition, 1915-1928), Vol. I, 420.

29.*Ibid.* and Meyer 1915, 77-78.

30.For these figures see *Salmonsens Konversationsleksikon* (2nd edition, 1915-1928), Vol.XIV, 43; Vol. VIII, 869; and Vol. I, 51.

31.See Hentzen 1908, 197; Hentzen 1933, 46; and Rode 1942, 62-63.

32.*Ibid.* and Hentzen 1933, 47.

33.For a history of Copenhagen see e.g. *Salmonsens Konversationsleksikon* (2nd edition, 1915-1928), Vol. XIV, 43-71.

34.Nielsen & Carstensen 1926, 19 and Rode 1942, 63-66.

35.Hentzen 1933, 48.

36.The system is described in for instance Søeborg 1916, 25 and Rode 1942, 64.

37.Hentzen 1908 and Windfeld-Hansen 1907.

38.Hentzen 1933, 61.

39.Søeborg 1916, 25-26.

40.*Ibid.*, 26-29.

41.Rode 1942, 70 ff. For the supply distances see Vinding & Frydlund 1915, table A.

42.For the early history of this company see *Nordsjællands Elektricitets og Sporvejs Aktieselskab 1902-1927* (1927) and Hansen 1977, 8-27.

43.*Nordsjællands Elektricitets og Sporvejs Aktieselskab* ... (1927), 54-63 and Hansen 1977, 18-20.

44.Angelo is interviewed in Bagge 1960, 121.

45. *Nordsjællands Elektricitets og Sporvejs Aktieselskab* ... (1927), 54-63; Hansen 1977, 18-20; and Bagge 1960.

46.*Nordsjællands Elektricitets og Sporvejs Aktieselskab* ... (1927), 62 and 68.

47.Vinding & Frydlund 1915, 216 and 219.

48.Vinding & Frydlund 1920, tables 1a and 3a and the electricity supply statistics of 1921/22 in Danmarks Statistik 1923, table IV.

49.For the 1914/15 figures see Vinding & Frydlund 1915, table 3a. The unknown ownership of the rural district system Halvrimmen is included as a co-operative company, as it was two years later (Vinding & Frydlund 1918, table 3a). For the 1923/24 figures see the electricity supply statistics in Danmarks Statistik 1925, tables I and II.

50.In the special case of Odder, the (rural) municipality participated in the Odder utility, which was a self-governing institution, which in turn participated in the co-operative society with consumer associations from the hinterland. Israelsen 1931, 5-11.

51.The establishment of district supply in Assens and Odder is briefly described in Wistoft et. al. 1991, 165-166. For the Assens arrangement see Beierholm 1935, 9-10.

52.See the electricity supply statistics of 1923/24 in Danmarks Statistik 1925.

53.*Sydøstsjællands elektricitets aktieselskab* ... (1937), 19-20 and 31.

54.See director J. Andersen's account in Ellert 1938, 16-20, and Meyer 1915.

55.*Brande elektricitetsværk* ... (1960), 12-15.

56.According to Rager 1919, 161 and 165.

57.Wistoft 1991, 165-166. For Assens see also *A/S Assens elektricitetsværk* ... (1961), 5-6.

58.Rager 1919, 166-167 and Wistoft et. al. 1991, 109-110. Rung is cited in Wistoft et. al. 1991, 110.

59.Ellert 1938, 15-16.

60.Hjul 1918.

61.Angelo 1952, 54-56 and Hansen 1977, 32-34.

62.Rager 1919, 159.

63.Jacobsen & Hallenberg 1934, 16-24; Meyer 1915, 77-79; Ellert 1938, 11 ff.

64.Rager 1917-18, 147-149.

65.Bache 1910-11.

66.E.g. *Beretning fra aarsmødet i Svendborg den 6te og 7de juli 1913* (Fredericia, 1913). Archive for the plant manager association *Foreningen af elektricitetsværkbestyrere i Danmark*, Danish Museum of Electricity.

67.The study is based upon a considerable number of more and less detailed jubilee publications of municipal utilities.

68.According to Frederiksberg utility director Winsløw. Winsløw & Rung 1909, 209.

69.Winsløw & Rung 1909, 209-210.

70.Hughes 1983, 218-219.

71.Klingenberg 1912, 731 (footnote 3). The article gives a survey of the different concepts used to evaluate the economic performance of electricity supply systems. Contrary to the load factor and the utilization time, the 'Betriebszeitfaktor' or running time factor relates to the running time of the engines regardless of the load, while the 'Ausnutzingsfaktor' or exploitation factor adds the back-up capacity to the load factor. For the utilization time of German power stations in 1905 see Engholm 1905, 168.

72.Engholm 1905, 171.

73.For Nykøbing Falster see Wollesen 1957, 81 (see also illustration on p. 79). For Horsens see Jensen et. al. 1931, 16 ff. For Hjørring see Thestrup 1996, 11.

74.For Middelfart see Mortensen 1935, 12-13. For Vejle see *Vejle kommunale elektricitetsværk* ... (1934), 50-52.

75.*Ibid.* Incidentally, the Vejle system had supplied villages outside the municipality from 1914 by direct current. Petersen 1984, 20.

76.Vinding 1910, 201-204. For Svendborg see also Hansen 1931, 12-17.

77.Vinding 1913b, table IIIA.

78.On Fredericia see *Foreningen af Elektricitetsværksbestyrere i Danmark. Beretning fra aarsmødet i Randers...* (1915), 12-13 and Petersen 1982, 16-21.

79."Elektricitet fra købstad til omegnen", *Danmarks kommunale efterretninger* Vol. 6 (1909-10): 532

80.Rager 1917-18, 35.

81.Hansen 1957, 9 and 12.

82. Petersen 1982, 16-21.

83.*Foreningen af Elektricitetsværksbestyrere i Danmark. Beretning fra aarsmødet i Randers...* (1915), 12-13 and Petersen 1982, 16-21.

84.For ownership of the means of production and the transmission/distribution systems in town-based systems see the 1923/24 electricity supply statistics in Danmarks Statistik 1925, tables I and III.

85.Westergaard 1931, 29-33.

86.For Brønderlev see *Brønderslev og oplands elektricitetsforsyning* ... (1986), 22. For Svendborg see Hansen 1931, 15-17. Se also the electricity supply statistics for 1923/24, table IIIb and 1931/32, IIIb.

87.*Elektricitetsselskabet ARKE* ... (1940), 8 ff. By 1917, the only system of similar size was the system in North-Western Jutland (1915), while the Randers system and the large rural systems on Zealand measured some 30-35 kms to their furthest consumer. Vinding & Frydlund 1920, table IIIA.

88.Therkildsen et. al. 1996, 29 ff. and 38 ff.

89.For Langeland see Langhorn & Külsgaard 1945, 8-15. For Morsø see Andersen 1985, 23-27. A similar arrangement existed between the municipality of Thisted and the co-operative society supplying the Northern hinterland.

90.*Sydøstsjællands elektricitets aktieselskab* ... (1937), 26.

91.Jørgensen 1946, 12.

92.For MES see Jørgensen 1946, 16-18; for Brande see *Brande elektricitetsværk* ... (1960), 12-15; for Hovedgaard see *Andelsselskabet Hovedgaard* ... (1986); for Vestbirk see Haugstrup 1946, 11-16; and for Falster see Holm 1937, 11 ff.

93.Holm 1937, 11-21.

94.Jørgensen 1946, 15-34. For data see also the electricity supply statistics of 1923/24, tables I, II and IIIb.

95.Holm 1937, 11-21 and *Sydøstsjællands elektricitets aktieselskab* ... (1937), 13-14.

96.In practice, the utility then amalgamated with the Hovedgaard utility and a transmission company to jointly exploit the Hovedgaard and Vestbirk power stations. Haugstrup 1946, 17 ff.

97.*Sydøstsjællands elektricitets aktieselskab* ... (1937), 36-37.

98.See the electricity supply statistics of 1923/24 in Danmarks Statistik 1925, table IIIb. Of the 31 town-based district systems, seven are excluded as they did not have hinterland supply, while the Århus system in Western Denmark is included even though it participated in a centralized system. The number of town based systems thus becomes 25. Electricity sales within the towns are of course excluded. And to the 13 rural district systems, the NESA and Gudenaa utilities are added although they participated in centralized supply systems, bringing the number of 'rural district utilities' at 15.

99.For the reach of these systems see the electricity suppy statistics of 1921/22, table IV.

100.Det Statistiske Departement 1962, 22-24.

101.This included for instance Nykøbing Falster, see Graae & Bützow 1932, 60.

Notes to Chapter 5

1. E.g. Klingenberg 1916, 333 and 347-348. For a survey of the development of centralized supply in Germany see Braun 1997, 78-86 and Hughes 1983, 287 ff., 295 ff. and 313 ff.
2. See for instance Rager 1917 and Brodersen 1917.
3. See Röss-Petersen 1917.
4. Angelo 1917, 317.
5. *Ibid.* 320-321.
6. For a historical analysis of the power exchange between the Nordic countries see Kaijser 1997.
7. Faber 1921a, 74.
8. Faber 1921b, 92.
9. For the following see particularly Faber 1921c. A previous and slightly different plan is presented in Faber 1921a, while Faber 1921b gives further technical details and motives.
10. The voltages used in the secondary and tertiary networks were determined with an eye to the social geography of the country. A distance of some 40 kilometers (at most 60 km) between provincial towns, and thus the primary transformers on the grid, made 15 kV an optimal compromize between capacity and economy in secondary transmission networks (yet most existing district systems used 10 kV, which could be included in the system). Likewise, a distance of some three kilometres between secondary transformer stations in larger villages or clusters of villages made 380/220 volts an appropriate distribution voltage. Faber 1921c, 6-8.
11. Krebs cited in Faber 1921c, 15.
12. Faber 1921c, 22-23.
13. See Rager 1921, 61 ff.; Faber 1921b, 85 ff.; and Faber 1921c, 9-10.
14. See "Danske Elektricitetsværkers Forening" in Gelardi (ed.) 1940, Vol. II, 28-43.
15. Faber 1924. For the work of the committee see also *Danske Elektricitetsværkers Forening 1923-1933...*, 55-57.
16. Faber et. al. 1926, 322.
17. Chief engineer Westergaard of the Randers municipal supply company cited in "Udvalget vedrørende samarbejde mellem elektricitetsværker", *Elektroteknikeren* Vol. 23 (1927): 307.
18. Jespersen 1930, 191 (nr. 792).
19. Cit. in *Betænkning (1. del)* ... 1929, 3 and 4.
20. For the following see *Ibid.*, 5-61 (Appendix A).
21. For the design of the centralized supply option see *Ibid.*, 13-15.
22. *Betænkning (1. del)* ... 1929, 15-31 and append. 1-5. Cit. from p. 34.
23. For a survey see Angelo 1952, 74-81 and Andersen 1952.
24. For a detailed account see Ellert 1943.
25. According to Ellert, the *Gudenaa* river was Denmark's largest, longest (158 km) and carrying most water (an average annual flow of 600 mill. m3 water at Tange, where the hydropower station was built). Its total fall was only 63 metres. Ellert 1943, 5-6 and 54.
26. Faber & Thomsen 1910.
27. Faber & Thomsen 1910, 66-68.
28. Ellert 1943, 35.
29. *Ibid.*, 70.
30. Röss-Petersen 1917, 493.
31. See the discussion in Angelo 1917, 321 ff.
32. Krarup quoted in Angelo 1917, 322.
33. Klingenberg 1916, 298.
34. Röss-Petersen 1917, 492.
35. For these countries see the survey in *Betænkning* .. 1929, appendix B; and Wissum 1956.
36. See Rasmussen 1982, 135. For a survey on state interference in Danish electricity supply see *Ibid.* 114-120 and 131-146.
37. Meyer et. al. 1906.
38. Meyer cited in Angelo 1917, 321.
39. Faber 1921c, 12 ff.
40. Rager cited in Faber 1921c, 20-21.
41. See the discussion in Angelo 1917, 321-325.

42. "Elektricitetsproduktionens Centralisation", *Lys og Kraft* Vol. 1 (1917), 51 and *Ibid.*, 123.
43. *P. A. Pedersen to barrister Liebe*, dated December 18, 1918. National Archives, *Elektricitetsrådet* (Archive nr. 1404), Journalsager 55/19.
44. *Fr. Johannsen to O. Liebe*, dated July 30, 1918. *Ibid.*
45. Pedersen 1919.
46. For the internal structure and members of the association see "Danske Elektricitetsværkers Forening" in Gelardi (1940), Vol. II: 28-43.
47. "Betænkning fra udvalget vedrørende regler for samarbejde ..." 1926, 323.
48. "Udvalget vedrørende samarbejde mellem elektricitetsværker", *Elektroteknikeren* Vol. 23 (1927), 306-312. See also *Danske Elektricitetsværkers Forening 1923-1933* ..., 55 ff.
49. *Betænkning (2. del)* ... 1933, 5.
50. *Ibid.*, 6.
51. *Ibid.*, 58.
52. According to the later Minister of Public Works Axel Sørensen, referred in "Stærkstrømslovens revision..." 1940, 198.
53. The 1935 Electricity Supply Act is presented in detail in Faaborg-Andersen 1935.
54. See Aubeck 1939, 342 ff.
55. Aubeck 1939, 344-346. Cited from p. 350.
56. *Ibid.*, 346-347.
57. Relevant discussions in the parliamentary system are referred in "Stærkstrømslovens revision" ..., 197-210.
58. *Betænkning angaaende rationel kraft- og varmeforsyning* ... 1940, 3-10 and 24 (cit. p. 8). For a comment see Rager 1941.
59. Henriksen 1946, 499.
60. See particularly Aubeck 1941.
61. "Beretning fra Elektricitetskommissionen af 1940" ... 1940, 373 and Aubeck 1941, 363.
62. Wistoft 1996; Wistoft et. al. 1992, 195 ff.; and *Elektricitetskommissionen - Elektricitetsrådet 1907-1982* (Copenhagen), 15.
63. For the early co-operation in the 1910s see for instance Angelo 1927, 42; Angelo 1952, 82-84; Rode 1942, 69-70; and *Sydøstsjællands Elektricitets Aktieselskab* ... 1937, 70.
64. In addition to these co-operations, in 1913-1914 a connection was established between Copenhagen and Frederiksberg, mainly to supply back-up capacity. However, this link was never used for actual energy exchange of any significance.
65. *Ibid.*
66. According to Angelo 1952, 84.
67. Angelo 1952, 84.
68. See primarily Angelo 1952, 84-85. For the extension of production capacity of NVE and SEAS see Ellert 1938, 27-28 and *Sydøstsjællands elektricitets aktieselskab* ... 1937, 68.
69. Cited from the 1921 contract in Ellert 1938, 30.
70. As a result NVE's production economy was improved remarkably; as it was proudly observed, the use of coal was reduced from 1.6 kg of coal per kWh produced to 1.2 kg per kWh already in the first month after the co-operation was started. *Ibid.*, 30.
71. *Sydøstsjællands Elektricitets Aktieselskab* ... 1937, 70.
72. Ellert 1938, 30.
73. Rode 1942, 83-84.
74. *Sydøstsjællands elektricitets aktieselskab* ... 1937, 70.
75. Angelo 1952, 80-81.
76. *Sydøstsjællands elektricitets aktieselskab* ... 1937, 71.
77. Angelo 1927.
78. From 3 x 70 mm2 to a 6 x 70 mm2. Rode 1942, 83-84 and Ellert 1938, 30.
79. Ellert 1938, 30-31.
80. Henriksen 1940, 361-362.
81. For the following see Wistoft et. al. 1991, 193-201. See also Andersen 1972.
82. According to Askgaard 1972a, 43.
83. For the co-operation between SH and German utilities see primarily Askgaard 1972b, 86-90 and Askgaard 1972a, 43-44.
84. Askgaard 1972a, 43-46, 53 and 67.

85. For a survey of the negotiations see *Betænkning (2. del) afgivet af udvalget angaaende fremtidige retningslinier ... 1933*, 3-5.
86. For the 1931 report see *Ibid.*, appendix A.
87. Cited from Sarøe 1933, 556.
88. For the 1932 report see *Betænkning (2. del) afgivet af udvalget angaaende fremtidige retningslinier ... 1933*, appendix B.
89. *Juul and Christiansen to Faber*, dated Feb. 26 1932. *Ibid.*, appendix 5.
90. According to Rasmussen 1982, 141 and Askgaard 1972b, 93-94.
91. Christiansen cited in Askgaard 1972b, 92.
92. Faber et. al. 1927, 312 and Wegener 1943, 429.

Notes to Chapter 6

1.Danmarks Statistik 1947, 80; 1952, 83; and *Foreningen af jydske jævnstrømsværker* ... (1960), 17. The agricultural counts of farms with autoproduction systems were rather incidental: The 1944 count was an incidental agricultural machinery census published with the agricultutal statistics of 1945, while the 1950 count was combined with the 1950 pig count. With regard to the geographical distribution of farms with autoproduction systems, in 1950 there were 472 farms with autoproduction systems on the islands and 1346 in Jutland.

2.The electricity supply statistics for 1945/46 estimate that there were 1700 autoproduction censuses, see Danmarks Statistik 1948, 95. Yet the agricultural censuses suggest a small decline from 2008 systems in 1944 to 1818 systems in 1950 in farms, see Danmarks Statistik 1945, 80 and 1952, 83.

3.For instance, it records only eight out of eighteen hundred butter factories with an autoproduction system. This may correspond to the number of autoproduction systems for electric power, which were introduced by butter factories only from the early 1930s. But it is unlikely that the more than two hundred butter factories with autoproduction systems for electric lighting in the 1920s (and probably still more) had all abandoned these systems, for this development started first in the second half of the 1930s (see chapter 11).

4.Danmarks Statistik 1939, tables IIIA and IIIB.

5.This total capacity was some two hundred megawatts. Danmarks Statistik 1952, 17. For comparable figures in 1960 see Det Statistiske Departement 1962, 48.

6.*Ibid.*

7.E.g. Danmarks Statistik 1952, 83.

8.Danmarks Statistik 1939, table IIIA.

9.Danmarks Statistik 1953, table IV.

10.Angelo 1913, 69.

11.Angelo 1946, 4.

12.Andresen 1913/14, 200 and 1915.

13.Rathlou 1918, 180.

14.Børresen 1934, 451.

15.Engholm 1926, 169.

16.Mogensen 1942b.

17.Mogensen 1942b, A115.

18.Danmarks Statistik 1952 (electricity supply statistics of 1950/51), appendix I.

19. "Elektriciteten i en cementfabrik...", *Elektroteknisk Tidsskrift* Vol. 17 (1912/13), 45.

20.The registers end in 1933. National Archives, Elektricitetsrådet, "Registre over anmeldelser 1908-33..", B 149, B150 and B151.

21.The sample included 5 cement factories in 1940 and 4 factories in resp. 1946 and 1952.

22. "Statistik over Industriens Kraftforbrug", *Elektroteknikeren* (1922), Vol. 18: pp. 111-117 (see also pp. 157-158).

23. Cit. from R. K. Meade, *Portland Cement* (Easton, Pa.: Chemical Publishing Co. 1930), cited in Witt, 107-109.

24.Drachmann 1932, 36-39.

25.*Ibid.*

26.Rønne 1938, M41.

27. *Ibid.* and Jacobsen 1949, 27-33.

28. For information about the power supply of the Rørdal factory, I am indebted to Henning Jensen of A/S Aalborg Portland.

29. For the following see primarily Holst 1936, 36-47.

30.According to Holst 1936, 37.

31.In fact the figure even underestimates the importance of electric drive, as the capacity of primary engines used both for driving machinery and generating electricity are included as non-electric machine drive in the table.

32.After 1951, the statistics of industrial production do not distinguish the paper industry as a single group, but included it in the industrial sector of 'paper and graphical industries.' Still, the autoproduction of electricity of other industries in this sector was marginal in 1951, and it may be assumed that the paper factories accounted for about all autoproduced electricity in this sector in the following decades. In 1960, 1970 and 1980 the autoproduction systems in this sector produced 83 GWh, 87 GWh and 60 GWh respectively. Danmarks Statistik 1962, table 8; 1973, table 7.02; and 1982, table 6.04.

33. Remarks: (1) For 1940 and 1951/52, the sample included 12 and 13 paper factories respectively; (2) In the calculation of the relative importance of electric power, primary power used exclusively for electricity generation is excluded, while primary power used both for direct machine drive and for electricity generation is included as non-electric machine power. Therefore, the importance of electric drive is underestimated. Sources: Danmarks Statistik, "Produktionsstatistik 1940", *S.M.* 4, 114, 3: Tables III, IV and V; "Industriel produktionsstatistik 1951", *S.M.* 4, 152, 1: Table VI; and "Industriel produktionsstatistik 1952", *S.M.* 4, 155, 3: Tables VII and VIII.

34. According to M.B. Mogensen, "Ny Maglemølle Kraftcentral", *Ingeniøren* (1939), Vol. 48: pp. E41-42 on p. E41.

35. *Ibid.*

36. "Elektricitetsværkerne 1939/40", *Statistiske Meddelelser* 4, 114, 1: Table I.

37. "Kraftcentralen Dalum Papirfabrik", *Tidsskrift for Maskinvæsen* (1951), Vol. 61: nr. 1 and Danmarks Statistik 1952, "Elektricitetsværkerne 1950/51", Table 1 and appendix I. See also Jacob Hansen & Knud Mortensen 1968, 308-309. In spite of ever more efficient public supply systems, paper factories remain major autoproducers today, although a substantial share of purchased electricity may be added. For instance, the largest Danish paper factory, Dalum paper factory, autoproduced 55% of its electricity consumption of 80 GWh in the late 1980s. The maglemølle factory autoproduced 'a minor share' of its electricity consumption. *Dansk papir i 100 år...*, 135 and 139.

38.Mogensen 1939, E.41. For the following see "Kraftcentralen Dalum Papirfabrik..." and Mogensen 1939.

39. Røs-Petersen, "Elektrisk Drift...", pp. 29-31.

40. *Dansk Elværksstatistik 1965/66* (Copenhagen: 1967): p. 31 [Description of public supply companies].

41.Danmarks Statistik 1952, 83.

42.Danmarks Statistik 1952, table VI. Out of 1818 farms with autoproduction systems in 1950, 472 were situated on the islands, 519 in Eastern Jutland, 270 in Northern Jutland, 491 in Western Jutland and 66 in Southern Jutland.

43.The aggregate results were published with the agricultutal statistics of 1945, see Danmarks Statistik 1947, 74 ff. See particularly tables V.1 and V.5.

44.*Ibid*, tables V.2 and V.5. Notably, for the farm groups of different sizes only the *percentage* of farms with autoproduction systems was published, which makes an exact reconstruction of the number of autoproducers pr. category of size impossible.

45.It is remarkable that the total number of farm windmills was decreasing: The agricultural machinery census of 1936 had recorded thirteen thousand farms with wind mills for agricultural works; almost all (about ninety percent) of these were situated in Northern and Western Jutland, where - as one observer put it for the case of Western Jutland - the landscape contained 'large flat areas with little hindrance for the free and steady speed of the wind' (Esbensen 1907, 391). In addition, some three thousand farms used windmills for pumping purposes in the fields. In 1944, however, the number of farms with windmills for agricultural purposes had decreased to less than eight thousand (including electricity production), while also the amount of farms with windmills in the fields had decreased slighty. For 1936 see Danmarks Statistik 1938, 9 and 17, and for 1944 see Danmarks Statistik 1947, 75.

46.La Cour 1903, 106-107.

47.Arnfred 1913, 620.

48."Færdige elektricitetsværker. 3. Gaardejer Boesens værk i Askov", *Tidsskrift for vindelektrisitet* 1904, 49-55.

49.For descriptions of these systems see "Færdige elektricitetsværker. 4. Ravnholt", *Tidsskrift for vindelektrisitet* 1905, 99-105; Bjerre 1905; and Larsen & Bjerre 1905.

50.For a list of systems designed by the D.V.E.S. company see "Repræsentantskabmødet for D.V.E.S. i Askov den 29. oktober 1908", *Tidsskrift for vindelektrisitet* (1908): 459-463.

51.Esbensen 1907.

52.Jens Pedersen 1907.

53.Ibsen 1905.

54.Arnfred 1916, 16.

55.For a good survey see Thorndal 1996.

56.For an analysis of the international success of Danish windturbines see Karnøe 1991. For an English version see Jørgensen & Karnøe 1995.

57.Thorndal 1996.

58.Christiansen 1940, 614 ff.; Balle 1946a, 275-276; and Knud Hansen 1942. For a survey of windgenerator producers see also Thorndal 1996, 348.

59.For this information I thank Jytte Thorndal of the Danish museum of electricity.

60.Danmarks Statistik 1961, 71 (table 1).

61.See Rosenstand Schacht's preface in T. Tougaard Pedersen 1961.

62.Wistoft et. el. 1992, 137-138. The number of farm hands decreased from 300.000 in 1945 via 150.000 in 1957 to 26.000 in 1972.

63.T. Tougaard Pedersen 1961.

64.Balle 1946b, 443-444.

65.Wistoft et. al. 1992, 138-140.

66.*Danmarks elforsyning. Fordeling og forbrug* ... (1986), 13.

67.According to director Prior in Angelo 1913, 75.

68.According to B&W engineer Blem in Angelo 1913, 75.

69.Of a total autoproduction of 332 GWh, the food industry accounted for 156 GWh. Danmarks Statistik 1982, table 6.04.

Notes to Chapter 7

1.Sources: The electricity supply statistics of the relevant years. The demarcation between local, district and centralized systems follows that of table 1.1. For 1970, the eight remaining systems were the isolated system on the island of Bornholm, the CHP plant of Randers, the smallest CHP plant in Copenhagen and five small hydropower systems exploited by the municipal utilities of Kolding, Holstebro, Esbjerg, Haderslev and Ribe. Except for the Bornholm system, these were all interconnected in the grid, but do not qualify as very large power stations.

2.Rung in Faber 1914, 164.

3.Rung 1934, 57-58.

4.Hasselbalch-Larsen 1938.

5.Cited from Petersen 1984, 29.

6.Hansen 1933, 338-339.

7.Rager 1928a, 13.

8.For the latter see the discussion in Angelo 1927, 49-52. The former occasion was for instance mentioned by Andreasen in Faber 1927, 308 (see also the footnote on p. 309), but is not included in the brief report of the meeting published in the municipal journal *Købstadforeningens Tidsskrift*.

9.Cited from Buemann's correspondence with the Southern Jutland regional utility in Askgaard 1972b, 94. See also Buemann's response to Angelo's talk in Angelo 1927, 49-51.

10.*Ibid.*

11.Bolet 1933, 336.

12.*Ibid.*, 337.

13.Bolet 1933, 337.

14.Director Sigvard Jensen in Rung 1934, 63.

15.Westergaard in Rung 1934, 68.

16.Westergaard 1946, 347.

17.For an illustrative case see Rager 1928b, 247-248.

18.Aubeck 1940, 218-219. Besides the Danish association of utilities, the arrangement involved two associations of electricians, the association of fire insurance companies, the association of plant managers and the association of producers and wholesale traders of electrotechnology.

19.Rager 1933-34, 533-534 and Sarøe 1933-34, 555-556.

20.Rager 1928a, 11-13.

21.Rager 1928a, 10-11.

22.Graae & Bützow 1932, 65.

23.Aubeck 1939, 350.

24.For Holbæk see Monrad Hansen 1961, 29-30. For Assens see *Assens elektricitetsværk* ... (1961), 24-29. The Holbæk expansion was not carried through however, due to the outbreak of the Second World War.

25.Elektricitetsrådet, *Kortfattet redegørelse vedrørende udvidelsen af Skagen elektricitetsværk* (1946) and *Elektricitetsrådet to Skagen elektricitetsværk,* April 11 1946. National archives, Elektricitetsrådet, Samarbejdudvalget, nr. 159.

26.*Elektricitetsrådet to Sorø elektricitstsværk* Marts 1, 1947. National Archives, Elektricitetsrådet, Samarbejdudvalg, nr. 299.

27.According to W. Hanning of the Frederikshavn municipal council in Elektricitetsrådet, *Referat af samarbejdudvalgets møde 30. april 1952*. National archives, Elektricitetsrådet (1404), Samarbejdudvalg, nr. 285.

28.Det statistiske departement 1962, tables 3 and 5.

29.Thostrup 1947, 31-34.

30.*Elektricitetsrådet to Frederikshavn kommunale værker*, May 20 1992. National archives, Ekeltricitetsrådet (1404), Samarbejdudvalg, nr. 285.

31. Elektricitetsrådet, *Referat af samarbejdudvalgets møde 30. april 1952* and *Elektricitetsrådet to Frederikshavn kommunale værker*, May 20 1952. National archives, Elektricitetsrådet (1404), Samarbejdudvalg, nr. 285.

32.In addition, the military was reluctant to participate financially in the expansion, unless external (NATO) finance was obtained, as it feared similar claims for its involvement in other construction projects such as roads, railroads and water works of military importance. *Ibid.* and *Forsvarsministeriet to Elektricitetsrådet*, May 13 1952. National Archives, Elektricitetsrådet, Samarbejdudvalg, nr. 285.

33.However, during the 1950s a majority in Parliament rejected the situation of allied forces in Denmark. Still, the naval base at Frederikshavn was considerable expanded.

34.According to Hanning in Elektricitetsrådet, *Referat af samarbejdudvalgets møde 30. april 1952*. National archives, Elektricitetsrådet (1404), Samarbejdudvalg, nr. 285.

35.Det statistiske departement 1962, 21 and tables 3 and 5.

36.*Dansk Elværksstatistik* ... (1973), 18.

37.For a brief survey see *Københavns varmeværker* ... (1950), 11-16.

38.*Københavns varmeværker* ... (1950), 17-19. For Fåborg see Hansen 1957, 13, and for Slagelse see Skaarup 1959, 37.

39.For 1935 see Gertsen 1935, 369. For 1954 see *Dansk Elværksstatistik 1954/55* ..., tables 1, 3 and 8 and Bak 1955, 317-318.

40.Gertsen 1935, 369 ff.

41.Hansen 1957, 12-13.

42.Jørgensen 1981, 122-124 and Westergaard 1931, 25.

43.Wegener 1943, 432-433 and "Fælleskraftcentralen. Diskussionen giver genlyd landet over", *Vejle Socialdemokrat* November 24, 1943.

44.Elektricitetskommissionan af 1941 ... (1946), 12-19.

45.Bak 1955.

46.Aubeck et. al. 1946, 16-17 and appendix 6.

47.Aubeck et. al. 1946, 17. See also Westergaard 1946, 344.

48.For instance, an expansion with a 6.5 MW steam turbine in 1949 was motivated - besides by a new large contract to supply a nearby cement factory, the need for back-up and the bad economic performance of older engines - by the rapid increase in heat sales. Randers kommunale elværk, *Forberedende anmeldelse af produktionsmidler*, December 29 1946. National Archives, Elektricitetsrådet, Samarbejdudvalg, nr. 179. See also Jørgensen 1981, 122-124 and Westergaard 1931, 25.

49.Elektricitetsrådet, *Teknisk-økonomisk redegørelse vedrørende en anmeldt udvidelse af Randers kommunale elværk med et turbineanlæg på 9 + 5.2 MW (evt. 12.5 + 9 MW)* and *Referat af elektricitetsrådets møde den 12. november 1954 med byrådsudvalgene i Aalborg or Randers samt Midtkrafts bestyrelse, de tekniske ledelser fra de kommunale værker i Aalborg og Randers samt for Midtkraft*, National Archives, Elektricitetsrådet, Samarbejdudvalg, nr. 179.

50.One compromize was that the Randers municipality would only pay a reduced capacity fee to the centralized system (that is, it paid only a reduced share of the investments). Another was that the director of the Ålborg utility promised not to take over electricity sales to the large transmission company of the Randers hinterland ELRO (which represented a major electricity demand), which had recently gained independence from the Randers municipality. The Århus representatives promised to compensate the Randers municipality financially for its corresponding investment in the grid, if the Århus utility would gain this company as a customer. *Ibid.* and *Randers Amtsavis*, November 16 1954.

51.Sørensen 1958, 349.

52.*Dansk elværksstatistik 1960/61*..., tables 1 and 5 and *Dansk elværksstatistik*... 1970, tables 1 and 5.

53.*Dansk elværksstatistik 1974-75* ..., p. 21 (nr. 152). By 1975 the electricity production capacity in the Randers power station was reduced from 41 MW to 21 MW, and electricity production was reduced from 118 GWh in 1970 to 93 GWh. *Ibid.*, table 3.

54.*Dansk Elværksstatistik* ... (1973), table 1.

55.Sørensen 1958, 348; Hansen 1957, 17; and Det Statistiske Departement 1962, table 5.

56.According to plant manager Skaarup 1959, 26-27.

57.Skaarup 1959, 20, 26-27, 37-40 and 44 (annual production until 1958/59).

58.Mogensen 1959, 359. Technologically, the plant started as a combined heat and power plant, using the four existing boilers and rebuilding the two condensation-turbogenerators to back-pressure turbogenerators. Each turbine had a heat capacity of 10 Gcal/h and an electricity capacity of 2.5 MW.

59.This also concerns the case of the Kolding plant below. According to the electricity supply statistics of 1960/61 the Kolding and Slagelse electric utilities merely purchased electricity partly from the centralized system, partly from 'private' producers. The amount of electricity (some 8 GWh) and 3 GWh respectively) purchased from private producers, however, corresponds to the annual production of their CHP plants. Det Statistiske Departement 1962, tables 3 and 5.

60.Mogensen 1959, 360-361.

61.Aubeck 1939, 344.

62.Buemann in Angelo 1927, 49.

63.Andersen 1985, 28-30. The Morsø system expanded its power station in 1926 and 1948, the Thisted system in 1936 and the Thy system in 1924, 1930, 1940 and 1947. Det Statistiske Departement 1962, pp. 28 and 35.

64.Kerstens 1926, 386; Buemann in Angelo 1927, 52; and *Dansk Elværksstatistik* ... (1973), 16 (nr. 022) and 19 (nr. 055).

65.Bekkevold 1939, 47-48.

66.Mayor Christensen cited from the newspaper *Aarhus Amtstidende* in Rager 1933-34, 534.

67.Rager's address in the second chamber of Parliament, dated October 24, is cited in Rager 1933-34, 534-536.

68.Bidstrup is cited from the newspaper *Vejle Amts Avis* in Rager 1933-34, 534.

69.Sarøe 1933, 556.

70.The contract is reprinted in *Beretning om den sydøstjydske samleskinne* ... (1959), 21-38.

71.Sarøe 1934, 83.

72.For a detailed account of events from the point of view of the partnership see Bekkevold 1939, 48-55.

73.Wistoft et. al. 1992, 29-30.

74.Wegener 1943, 430.

75.Aubeck 1941, 362.

76.Aubeck 1941, 365-367.

77.Aubeck 1941, 364.

78.Askgaard 1972a, 58-59.

79.Wegener 1943, 431.

80.*Beretning om den sydøstjydske samleskinne* ... (1959), 17.

81.See paragraph 9 in the contract, which is reprinted in *Beretning om den sydøstjydske samleskinne* ... (1959), 39-50.

82.Wegener 1943, 430.

83.Wistoft et. al. 1992, 175.

Notes to Chapter 8

1.Source: Electricity supply statistics (see tables 1.1 and 7.1).

2.Angelo 1917, 320-321.

3.Krebs in Angelo 1917, 322.

4.Hasselbalch-Larsen 1938.

5.According to an advertisement, the firm at least sold accumulator batteries to electric power stations, cars and radios two decades later. See the advertisement in *Elektriciteten* Vol. 12 (1949), nr. 1, 13.

6.For a summary and a comment see "Jævnstrøm - vekselstrøm", *Elektroteknikeren* Vol. 23 (1927), 176-178.

7."Jævnstrøm - vekselstrøm", *Elektroteknikeren* Vol. 23 (1927), 176-178.

8.About two-thirds of the village local systems were established before the war, while most district utilities were established during and after the First World War. The electricity supply statistics of 1931/32 in Danmarks Statistik 1933, 73.

9.For a reprint of the discussion see Johansen et. al. 1913. For a brief biography see Jespersen (1930), nr. 1255.

10.E.g. Rung 1917 and Juul 1917.

11.Vinding & Frydlund 1918, 86.

12.Haar 1927. For a brief biography see Jespersen 1930, nr. 1482.

13.Angelo 1918, 187.

14.E.g. Rung 1920.

15.Brix-Pedersen 1949. For a brief biography see *Dansk civilingeniørstat 1955* (Copenhagen, 1956), nr. 4797.

16.For rural utility plant manager associations and members see Petersen et. al. 1938 (Funen) and Gelardi (ed.) 1940, 413-473.

17.See Pedersen et. al. 1938, 39 ff.

18.Villemoes 1935, 4.

19.Mondrup 1938, 5.

20.Notably, another fraction in DEF, the association of rural district utilities DOFF [*Danske Oplandcentralers og Forsyningsselskabers Forening*, 1934], can hardly be taken to represent small rural producing actors. As the constitution of its executive committee reflects, it represented the interests of the very large district utilities such as the Southern Jutland utility and the Gudenaa partnership in Western Denmark and the large rural district companies of Eastern Denmark, actors which worked for centralized supply instead of against it. Furthermore it included a number of pure transmission companies of town hinterlands, which did not have a stake in decentral production either, as their aim was merely to purchase the cheapest possible energy and transport it to the consumers. Gelardi (ed.) 1940, 50-51.

21. "Vort blad", *Elektriciteten* Vol. 1 (1938), nr. 1: 3.

22.Jensen 1938 and 1939 (cit. p. 9).

23.E.g. C.E. Jensen 1954.

24.Villemoes 1938a, 12.

25.See primarily Villemoes 1938b. See also 1936 and 1938a.

26.Mondrup 1939a.

27.Mondrup 1939b, 10.

28.Mondrup 1947a.

29.Mondrup 1943, 12 and 1944, 10-12.

30.C.E. Jensen referred in "Det tredje jydske medlemsmøde i Aalborg 23. januar 1954", *Elektriciteten* Vol. 17 (1954): 3-8 on p. 4.

31.Bech 1954, 4.

32.Mondrup 1954, 6.

33.Mondrup 1947a, 3.

34."Jævnstrømsværkerne vil bevare selvstændigheden. Udtalelser af formanden for de fynske jævnstrømsværkers sammenslutning", *Elektriciteten* Vol. 11 (1948), nr. 2: 4.

35.Chairman Rs. Petersen in "Jævnstrømsværkernes fællesmøde", *Elektriciteten* Vol. 12, nr. 11: 3-6 on p. 3.

36.See Pedersen et. al. 1938, 39 ff.

37.Rager 1936, 10.

38."Det jydske aarsmøde i Ulfborg", *Elektriciteten* Vol. 2 (1939), nr. 6 and 7.

39."Det jydske aarsmøde i Ulfborg", *Elektriciteten* Vol. 2 (1939), nr. 6 and 7.

40.Mondrup 1940, 5.

41.Chr. Jensen 1939.

42.H. Jensen 1939.

43.Mondrup 1942, 12.

44.Jensen 1940. According to the 1937-38 electricity supply statistics, the average efficiency of the steam power stations in Århus, Åbenrå, Ålborg, Randers, Kolding and Horsens was 5517 heat units per net produced kWh. Including 25% losses, a kWh supplied to the distribution network of a local system would cost 6898 heat units. By contrast, a 25 hk Bukh diesel engine average load worked at 5692 heat units per kWh or merely 82,5% of the fuel efficiency of the steam power stations.

45.Mondrup 1940, 10-11.

46.Mondrup 1941, 6-8.

47.Mondrup 1941. More than eighty utilities used suction gas engines, while the number of village or small town local systems using windmills increased from forty-three in 1940 to some eighty in 1942, when it stabilized. See the statistics for production of wind electricity in *Elektriciteten* Vol. 4 (1941), nr. 12, 4; Vol. 5 (1942), nr. 6, 6; and Vol. 8 (1945), nr. 5, 11.

48. See primarily Electricity Council, *Redegørelse vedrørende teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af manskinanlægget paa Asaa elektricitetsværk* (1936); *Redegørelse vedrørende teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af Asaa elektricitetsværk* (1948) in National archives, Elektricitetsrådet (nr. 1404), Samarbejdudvalg, nr. 73.

49.*C. E. Jensen to Electricity Council* (July 15, 1936). National archives, elektricitetsrådet, samarbejdudvalg, nr. 73.

50.See Electricity Council, *Redegørelse vedrørende teknisk-økonomisk undersøgelse ... af Asaa elektricitetsværk* (1948) and *Erklæring fra elektricitetsrådet i henhold til lov nr. 169 af 11. maj 1935 vedrørende en den 7. juni 1948 anmeldt udvidelse af Asaa elektricitetsværk* (1948). National archves, ..

51.Sources: Electricity Council, *Redegørelse vedrørende teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af manskinanlægget paa Asaa elektricitetsværk* (1936); *Redegørelse vedrørende teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af Asaa elektricitetsværk* (1948); and Brix Pedersen & Kamp Jørgensen, *Asaa elværk. Redegørelse vedrørende forskellige udvidelsesmuligheder for fremskaffelser af mere effekt* (1955). National archives, Elektricitetsrådet (nr. 1404), Samarbejdudvalg, nr. 73.

52.*Vendsyssel Tidende*, November 25 1948.

53.Brix Pedersen & Kamp Jørgensen, *Asaa elværk. Redegørelse vedrørende forskellige udvidelsesmuligheder...* (1955).

54.*Vendsyssel tidende*, June 23 1955.

55.*Ragnvald Pedersen (Aså) to Electricity Council* (July 15, 1955). National archives, ...

56.Danmarks Statistik 1948, 87.

57.*Elektroteknikeren* Vol. 23 (1927), 176.

58.Electricity Council, *Redegørelse vedrørende teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af Moseby elektricitetsværk* (1936) *and Electricity Council to Ministry for Public Works* (January 18, 1937). Both in National archives, Elektricitetsrådet, Samarbejdudvalg, nr. 149.

59. "Erklæring fra elektricitetsrådet", *Maanedsmeddelelse for foreningerne af bestyrere paa landelektricitetsværker i Danmark* Vol. 2, November 1936: 10.

60.Mondrup 1947b, 15.

61.Electricity Council, *Teknisk-økonomisk redegørelse vedrørende forberedende anmeldt udvidelse af Faster elektricitetsværk* (1956). National archives, Elektricitetsrådet, Samarbejdudvalg, nr. 4.

62."Radsted elektricitetsværk", *Elektriciteten* Vol. 10 (1947), nr. 4: 19.

63.Electricity Council, *Teknisk-økonomisk redegørelse vedrørende en forberedende anmeldt udvidelse af Uglev elektricitetsværk med et 500 kW diesel aggregat* (1964). National archives, Elektricitetsrådet, Samarbejdudvalg, nr. 56.

64.Electricity Council, *Teknisk-økonomisk redegørelse vedrørende en forberedende anmeldt udvidelse af Jelling elektricitetsværk* (1956). National archives, Elektricitetsrådet, Samarbejdudvalg, nr. 87.

65.Electricity Council, *Teknisk-økonomisk redegørelse vedrørende en forberedende anmeldt udvidelse af Sønderso elektricitetsværk med et 200 hk dieselaggregat* (1954) and *Sønderso elektricitetsværk to Electricity Council*, July 25 1954. National archives, Elektricitetsrådet, Samarbejdudvalg, 174.

66.Mondrup 1948, 581-582.

67.Jensen 1948, 4.

68.Danmarks statistik 1952, table V.

69.Det statistiske departement 1962, table 8.

70.Elektricitetsrådet, *Redegørelse vedrørende en teknisk-økonomisk undersøgelse i anledning af en anmeldt udvidelse af Tarm elektricitetsværk*, March 22 1947 and *Tarm elektricitetsværk to Elektricitetsrådet* April 15 1947. National archives, Elektricitetsrådet (1404), Samarbejdudvalg, nr. 2.

71.See *Ikast el- og varmeværk* ... (1973), 35 ff. and Mortensen (ed.) 1987, 27 ff.

72.Jørgensen 1946 and Det statistiske departement 1962, p. 27 and table 5.

73.See *Dansk elværksstatistik 1970-71* (1973), pp. 24 ff. and table 5 (Brande nr. 241, MES nr. 246, Horsens hinterland nr. 222, Brende mølle 542).

74.Wistoft et. al. 1991, 69.

75.*Langelands Folkeblad*, January 7 1966.

76.Electricity Council, *Teknisk-økonomisk redegørelse vedrørende en forberedende anmeldt udvidelse af Fejø elektricitetsværk med en brugt 240 hk/160 kW dieselaggregat til erstatning for et ældre på 60 hk/40 kW* (1960). National archives, Elektricitetsrådet, Samarbejdudvalg, nr. 55 and *Næstved Tidende*, August 14, 1964.

77.About half of these island systems used low voltage, direct current distribution, while the other half used low voltage, alternating current distribution. The system on Anholt, finally, was soon to be expanded to a district system using ten kilovolts transmission. *Dansk elværksstatistik 1970-71* (1973), table 3.

Notes to Chapter 9

1.Wistoft 1994, 174.

2.Wistoft 1994, 174.

3.OECD 1956, table 12.

4.*Ibid.*, tables 14 and 16.

5.*Dansk Elværksstatistik 1970-71* ..., table Q and Wistoft et. al. 1992, 111.

6.According to Svend Aage Hansen, the Danish GNP at factor costs increased from 8.127 mill. dkk in 1939 to 81.610 mill. dkk in 1967. The contribution of the secondary sector to the GNP increased from 32% to 40%, that of the tertiary sector remained stable at 50% and that of the primary sector decreased from 20% to 10%. Svend Aage Hansen 1970, 11.

7.In 1930 the primary sector employed for 30% of the total population, the secondary sector 29% and the tertiary sector 11%. By 1960 these figures were 19%, 35% and 16% respectively. Nielsen & Wagner 1994, 38 after H. P. Clausen et. al. (ed.), *Danmarks Historie* Vol. 9 (Copenhagen, 1985), 34.

8.Danmarks Statistik, *Produktionsstatistik 1940*, 33 and *Produktionsstatistik 1952*, table VIII.

9.Wistoft et. al. 1992, 111.

10.According to NESA's chief engineer. See Brodersen 1940, 137.

11.Angelo 1940, 3-4 and Angelo 1952, 86-88.

12.Ørum 1940, 551 and Kristensen & Olsen 1981, 81.

13.Buhl 1961, 106.

14.See Ørum 1940.

15.Kristensen & Olsen 1981, 81.

16.For a detailed description see Brodersen 1949.

17.Brodersen 1949, 431. Also grate boilers had to be adapted to the new fuel of lignite, but for the powdered coal boilers this transition was still more problematic. Due to its high water content, the lignite required an extended drying procedure with large and expensive equipment (reducing the water content from e.g. 50% to 20%) before it could be grinded and burned. The drying equipment of the IFV power station, however, was not a success. Bak 1946, 35 and 1963, 219.

18.According to Kristensen & Olsen 1981, 102.

19.Kristensen & Olsen 1981, 82 (figure) and 102.

20.*Betænkning angaaende rationel kraft- og varmeforsyning* ... 1940, 1-2 and 10.

21.*Elektricitetskommissionen af 1941. Teknisk Underudvalg* ... 1946, 5-6. See also Wistoft et. 11. 1992, 53.

22.Elektricitetskommissionen af 1941. Teknisk Underudvalg ... 1946, 5-7.

23.At any rate, by 1960 the two schemes would approach each other due to the increased demand - scheme I would demand more power stations because the power stations would be fully used (unless larger units than the 36 MW units in the calculations were used), while scheme II would demand a 120 kV grid as a result of the increase of the capacity of the co-operating power stations. *Ibid.*, 8-12.

24.*Ibid.*, 14-19.

25.*Ibid.*, 12-14. Cit. on p. 14.

26.*Ibid.*, 19-22.

27.E.g. Wistoft 1994, 53-54.

28.Henriksen 1946, 516.

29.For the following see Bekkevold 1939, 53-55.

30.Bekkevold 1939, 55.

31.Petersen 1984, 29.

32.For the early course of events see Bekkenvold 1939, 50-55.

33.However, the Electricity Council rejected these calculations, showing that purchase was cheaper than either decentral expansion of a joint power station. In response Bekkevold took the effort of defending the joint power plant scheme; again the argument centred on the premises of the calculations, as Bekkevold particularly criticised the fact that the council had calculated with a 50% higher fuel consumtion for the joint power station compared to the Åbenrå power station. This figure, which made all the difference, was unreasonable. The parties then agreed that the differences between the schemes were marginal relative to uncertainties in the premises of the calculation, and that further calculations were pointless. Bekkevold 1939, 52-53.

34.Petersen 1982, 55.

35.For a brief account see Petersen 1984, 35-36.

36.See also *Beretning om den Sydøstjydske samleskinne* ...

37.Henriksen 1946, 516.

38.Hjort 1941, 624.

39.Rager 1949, 127.

40.According to Hjort, electricity costs in modern large power stations (producing 100 GWh annually) would amount to merely 3 øre/kWh in pre war prices, of which 1.5 øre interest and repayment and 1 øre fuel. In smaller and older power stations (producing 15-20 GWh annually), these costs would be some 10 øre/kWh, of which 3-4 øre for interest and repayment and 2-3 øre to fuel. Including expansion of the existing 60 kV grid (50 mill. dkk, calculating with capital costs of 10% meaning approx 1 øre/kWh), the electricity costs in the centralisation scheme were 4-5 øre/kWh lower than in a scheme of decentralised production.

41.Hjort 1941, 623-626.

42.Westergaard 1946, 345.

43.Vendelbjerg 1987, 23-24.

44.Hansgaard 1990, 44-45, Stensig 1996, 21 ff. and *Dansk elværksstatistik 1960/61*, 18 ff. and table 3.

45.Langhorn 1985, 15 ff.; Hansen 1957, 16-17; and Sørensen 1958, 348.

46.N. K. Kristensen 1952.

47.For a survey see Sørensen 1958, 348-353.

48.*Ibid.*

49.*Dansk elforsyning 1960/61...*, 17-18 and table 3.

50.Sørensen 1953.

51.For a detailed account see Wistoft et. al. 1992, 97-105.

52.See Møller 1949.

53.Møller 1949, 1011-1013.

54.*Ibid*, 1018. The 150 kV option was preferred because it was only slightly (5-10%) more expensive than a 120 kV grid, while it had a 54% higher transport capacity (70 MW over 100 km with a cos φ= 0.9). On the other hand, a 220 kV grid would be considerably more expensive than a 150 kV grid (32.5%), but had a more than twice as large transport capacity (153 MW over 100 kms, cos φ=0.9).

55.*Ibid.*, 1018.

56.Møller 1953, 348.

57.Møller 1953, 348-349.

58.Kramer 1955.

59.Jakobsen 1956, Jakobsen 1957 and Sørensen 1958, 344-347.

60.*Ibid.* In addition, with regard to the coordination of energy exchange in the system ELSAM built and operated a new central control centre. This control centre was physically situated at the power station of the Southern-Eastern Jutland partnership, centrally situated in the grid. A large telecommunication system facilitated central control and operation of the system: First, direct telephone lines were to facilitate contact between the ELSAM control centre and the control centres of the participating power stations. Second, telegraphy equipment would be used to communicate simple but frequent messenges. Third, remote measurement equipment measured the amounts of active and reactive power exchanged between the centralized power companies, as well as relevant variables of power transmission (voltage etc.). Fourth, measurement equipment indicated the activation of power switches in the system. Finally, the system included remote control of the primary transformer stations. Jacobsen 1956, 435-436.

61.For the state of the grid in 1961 see Jakobsen 1961, fig. 19.

62.See the discussion in Hjort 1949, 91-93.

63.Bagge 1949, 75-77.

64.Hjort 1949, 76-77. According to a study on a 500 kms 200 kV transmission line from Oslo in Norway via Sweden, accross the Sound to IFV's (and NESA's) central transformer station, which would have a capacity of some 100 MW (excl. losses of some 25 MW) and cost some 60 mill. dkk, electricity could be supplied in Denmark for 2 to 2.5 øre pr. kWh. This presupposed an annual transport of 600 GWh (6000 hours annually) of electricity, and was about a third of the production costs in steam power plants.

65.Bagge 1949, 75-77.

66.Bagge 1949, 78.

67.Bagge 1954, 5.

68.Hansen 1961, 49.

69.Det Statistiske Departement 1962, table 3.

70.Holm 1987, 68 and Det Statistiske Departement 1962, 28.

71.See Brodersen 1959.

72.For the following see primarily Wistoft et. al. 1992, 79-80.

73.Buhl 1961, 108 and Madsen 1960, 435.

74.For a graphical survey of energy exchange between Denmark and Sweden as well as the transport capacity of the submarine interconnections see Knudsen 1963, 278. For a broader historical survey see Kaijser 1997.

75.*Ibid.*, 432- 433.

76."Netmodellen", *Elektroteknikeren* Vol. 52 (1956): 109.

77.Torben Holm 1987, 61.

78.Wistoft et. al. 1992, 79.

79.Madsen 1960, 430-431.

80.*Købstadforeningens Tidsskrift* Vol. 59 (1948), 303-313.

81.Dorthe Uldall Petersen 1984, 41-44.

82.See H. Monrad Hansen 1961, 36-49.

83.Skaarup 1959, 25-34.

84.Sources: The respective elctricity supply statistics in Danmarks Statistik 1933, table II; 1942, 90-92;1952, 8-10; det Statistiske Departement 1962, tables a and c; *Dansk Elværksstatistik 1970-1*, tables a and c.

Notes to Chapter 10

1."Jævnstrømsværket", *Elektriciteten* Vol. 14 (1951), nr. 6: 17.

2.Mondrup 1945, 12.

3.Mondrup 1947b, 15.

4. "Jævnstrømsværkernes fællesmøde", *Elektriciteten* Vol. 12 (1949), nr. 11: 3-6.

5.Based on the survey of utilities in Det Statistikse Departement 1962, 15-37. Among rural transmission companies still purchasing power from the nearby municipality were the hinterlands supply companies of Lemvig and Silkeborg. For the Vendsyssel area see *Dansk Elværksstatistik 1970-71*, 16-17.

6.Det Statistiske Departement 1962, 20-21. For ELRO see also Dantoft 1994, 8-14.

7.Mondrup 1953, 6.

8.Mondrup 1947b, 15 and 1948, 582

9.Petersen 1950, 6.

10.Brix-Pedersen 1949.

11.Brix-Pedersen 1949, 10-12.

12.*Foreningen af jydske jævnstrømsværker* ... (1960), 16-18.

13.Mondrup 1951, 4.

14.Brix-Pedersen 1947; Mondrup et. al. 1951; and Villy Rasmussen 1959.

15.Mondrup 1959, 5.

16.Mondrup 1953, 4.

17."Land-elværkerne vil blive tvunget til en omlægning", *Elektriciteten* Vol. 22 (1959), nr. 4: 7.

18.See e.g. Mogensen 1942a; Bertelsen 1946;

19.*Foreningen af jydske jævnstrømsværker* ... (1960), 18.

20."Land-elværkerne vil blive tvunget til en omlægning", *Elektriciteten* Vol. 22 (1959), nr. 4: 7.

21.Petersen 1952, 8.

22.Rung 1905, 178.

23.Petersen 1950, 6.

24."Jævnstrømsværkerne på Lolland-Falster", Elektriciteten Vol. 20 (1957), nr. 10: 3-7 on p. 3.

25."Det fynske aarsmøde", *Elektriciteten* Vol. 14 (1951), nr. 3: 3-4.

26.Mondrup et. al. 1950.

27.*Elektriciteten* Vol. 28 (1965), nr. 12.

28."Vekselstrømspørgsmålet i Hedensted henlagt i fem år", *Elektriciteten* Vol. 20 (1957), nr. 3 5-6; "Hedensted elværk", *Elektriciteten* Vol. 22 (1959), nr. 11: 12-13 and Vol. 23 (1960), nr. 7: 4.

29. "Kongsvad elværk", *Elektriciteten* Vol. 19 (1956), nr. 11: 16 and *Elektriciteten* Vol. 21 (1958), nr. 4: 12-14.

30."Hammerum elektricitetsværk", *Elektriciteten* Vol. 10 (1947), nr. 3: 14 and nr. 9: 16.

31.*Elektriciteten* Vol. 22 (1959), nr. 5: 12-13.

32."Asaa elværk", *Elektriciteten* Vol. 22 (1959), nr. 10: 13 and Vol. 23 (1960), nr. 4: 10.

33. "Dronninglund går over til vekselstrøm", *Elektriciteten* Vol. 24 (1961), nr. 9: 9. See also *Elektriciteten* Vol. 24 (1961), nr. 5: 8.

34.Mondrup 1954b, 10.

35.For Dybvad see "Dybvad Elværk", *Elektriciteten* Vol. 20 (1957), nr. 8: 16; Vol. 21 (1958), nr. 8: 13-14; and Vol. 23 (1960), nr. 5: 12. For Ulfborg see "Ulfborg elværk", *Elektriciteten* Vol. 23 (1960), nr. 2: 13-14. For Tjæreborg see "Tjæreborg Elværk", *Elektriciteten* Vol. 22 (1959), nr. 6: 11-12 and *Elektriciteten* Vol. 25 (1962), nr. 4: 11. For Skals see "Skals Elværk", *Elektriciteten* Vol. 20 (1957), nr. 6: 18 and Vol. 22 (1959), nr. 3: 12.

36.Wistoft 1994, 187.

37.*Ibid.*

38.For Fjaltring see "Fjaltring og omegns elværk", *Elektriciteten* Vol. 20 (1957), nr. 8: 16. Another case, which concerns a privately owned utility, is that of the Ry watermill. The utility supplied hydroelectricity to two co-operative societies of consumers, which supplied the station town of Ry and the old village respectively; this included several hotels in the touristic Himmelbjerg area at a spply distance up to six kilometres, which put a strain on the 440 volts distribution system. The utility owner then decided to adapt the power station for partial alternating current production, supplying ten kilovolts to the old village, where it was converted to direct current for distribution. Wistoft et. al. 1992, 63-64.

39.For Ranum see *Elektriciteten* Vol. 24 (1961), nr. 10: 12. For Viuf see "Viuf elværk", *Elektriciteten* Vol. 21 (1958), nr. 3: 11-12.

40."Et jævnstrømsværk nedlagt", *Maandesmeddelelser for foreningerne af bestyrere på land-elektricitetsværker i Danmark*, November 1937: 3. For the pricing policy of the EASV utility see Oksen 1994, 43-44.

41.Mondrup 1958, 3.

42."Mørke elektricitetsværk", *Elektriciteten* Vol. 19 (1956), nr. 2: 21-22.

43. "Det lyder som et eventyr",*Maandesmeddelelser for foreningerne af bestyrere på land-elektricitetsværker i Danmark* Vol. 25 (1960), May: 5-8.

44.For Jelling see "Jelling Elværk", *Elektriciteten* Vol. 23 (1960), nr. 3: 10-12. For Tørring see "Tørring Elværk", *Elektriciteten* Vol. 21 (1958), nr. 9: 17-18; "Tørring elværk tager første skridt til at gå over til vekselstrøm", *Elektriciteten* Vol. 21 (1958), nr. 11: 12-14; "Tørring Elværk", *Elektriciteten* Vol. 22 (1959), nr. 3: 13-14.

Notes to Chapter 11

1.Danmarks Statistik 1973, 177 and table 7.02.

2.Sources: Danmarks Statistik 1923-1952; Det Statistiske Departement 1962, table q; and *Dansk elværksstatistik* 1975-76, 29.

3.Hesselmans 1995, 65-66.

4.Hughes 1983, 220-224.

5.Angelo 1913.

6.*Ibid.*, 72.

7.Hallenberg 1914, 15-16.

8.See Due Jeppesen 1927, table I and H. A. Jensen 1937, table I for information on electricity prices of the member utilities of the association of plant managers.

9.Vinding & Frydlund 1915 gives detailed information on pricing systems of individual utilities.

10.Børresen 1934, 450-451.

11.Engholm 1933, 569-570.

12.Ranløv 1946, 98.

13.Lichtenberg 1946.

14.Henriksen et. al. 1948.

15.Angelo 1951.

16.Odel 1954.

17.P. Gregers Petersen 1958, 362.

18.See "FKE's generalforsamling", *Elektroteknikeren* Vol. 54 (1958), 1958 and "De købstadkommunale værker", *Elektroteknikeren* Vol. 56 (1960), 277.

19. For the flour industry in the 19th century see van der Vleuten 1994; for the first half of the 20th century, see primarily Ranløv 1943 and Paulli 1943.

20.At least in the early 1890s, see Baumann 1892/93.

21.Poul I. Jensen 1923, 58-59. In addition, an often heard disadvantage of DC motors was (contrary to electric lighting) the danger of fire caused by the sparks from the commutators. "Brandfaren ved Elektricitet. En Demonstration i Koblingstaarnet ved Aastrup Bro", *Møllen. Tidsskrift for Skandinavisk Mølleindustri* (1924), Vol. 38: pp. 193-194.

22. Cit. from Jensen, "Elektrisk Kraft i Møller...", p. 58.

23. Mygh, "Dampmøllen i Nykøbing på Falster..", p. 31.

24. Cit. from "Elektricitetspriserne", *Den Danske Møller* (1946), Vol. 19: nr. 7. See also "Elektricitetspriserne", *Den Danske Møller* (1943), Vol. 16: nr. 4 and "Elektricitetspriserne", *Ibid.* nr. 10.

25.Liselotte Mygh, "Dampmøllen i Nykøbing på Falster", *Fabrik og Bolig* (1995): nr. 2, pp. 3-36 on p. 31 and *Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 627/49 (Horsens Dampmølle): Letter from Horsens Dampmølle to Elektricitetsrådet on October 10, 1949.

26."Elektrisk drift i møller", *Elektroteknisk Tidsskrift* Vol. 19 (1915), 108-110.

27."Elektrisk Drift i Møller", *Elektroteknisk tidsskrift* Vol. 19 (1915), 108 and 110. For a similar argument see "Elektricitet og Mølledrift", *Elektroteknisk tidsskrift* Vol. 16 (1911/12), 127.

28.The statistics of production also included up to thirty larger bakery-mills, bringing the number of flour factories on 75 in 1940 and 59 in 1951. Danmarks Statistik 194x, table V and 1953, table VI.

29.Sources: Danmarks Statistik 1908, table III.A; 1917, table V; 1929, table IV; 1939, table III.B; 1953b, table II.B. Flour factories are defined as flour producers with more than five workers.

30. "Den elektriske valsemølle i Svinninge", *Elektroteknisk tidsskrift* Vol. 29 (1916), 192-193.

31.*Møllen. Tidsskrift for Skandinavisk mølleindustri* Vol. 32 (1917), 116 and Due-Jeppesen 1917, table 1 (nr. 5).

32.*Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 1292/40 (Slagelse Dampmølle): "Anmeldelsesskema for et Jævnstrømsanlæg" (1909), "Rapport over et af Ing. Stellfeld Hansen den 6. Januar 1933 foretaget eftersyn af A/S Slagelse Dampmølle Elektricitetsværk" and "Teknisk Anmeldelse af en Transformatorstation" (1940). See also Skaarup 1959, 23, 36.

33.Kristjansen 1941a.

34.E.g. "Elektricitetspriserne", *Den danske møller* Vol. 16 (1943), nr. 4, 3.

35."Elektricitetspriser og -Tariffer bør reguleres",*Den Danske Møller* Vol. 18 (1945), nr. 7, 4.

36."Elektricitetspriserne", *Den danske møller* Vol. 18 (1945), nr. 10, 3.

37.Cit. from "Elektricitetspriserne", *Den Danske Møller* (1946), Vol. 19: nr. 7. See also "Elektricitetspriserne", *Den Danske Møller* (1943), Vol. 16: nr. 4 and "Elektricitetspriserne", *Ibid.* nr. 10.

38.*Munke mølle to Electricity Council*, Oktober 15 1943. National archives, Elektricitetsrådet, samarbejdssager, nr. 346.

39.Mødeprotokol November 16, 1943. *Ibid.*

40."Odense Elektricitetsværk ændrer sin Prispolitik", *Fyns Venstreblad* (Feb. 28, 1946).

41.*Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 629/50 (A/S Munke Mølle, Odense): "Teknisk Anmeldelse af en elektrisk Central, Understation eller Lign." (1946).

42.*Ibid, Letter from Munke Mølle to Elektricitetsrådet* on November 10, 1950.

43.For this rationalization see Buksti 1982.

44.Harald Jensen 1962, 127 amd 128-130.

45."Mejeridriften og elektricitetsværker", *Elektroteknisk tidsskrift* Vol. 19 (1915), 21.

46.*Mælkeritidende* Vol. 29 (1916), 441.

47.Hasselbalch-Larsen 1936, 293.

48.A. P. Hansen 1917.

49.Chr. Jørgensen 1920.

50.Niels Sørensen 1920.

51.Hasselbalch-Larsen 1936, 293.

52."Mejeridriften og elektricitetsværker", *Elektroteknisk tidsskrift* Vol. 19 (1915), 21.

53.A. P. Hansen 1917.

54.For surveys of the history of dairy pasteurization equipment see e.g. Kjærgaard-Jensen 1944, 195 ff. and Harald Jensen 1950. See also Kloster 1980.

55.According to Harald Jensen 1936, 296.

56.Harald Jensen 1962, 129 and 137-140.

57.E.g. Harald Jensen 1962, 129 and Wistoft et. al. 1991, 272.

58.J. F. Engberg 1940a.

59.Gotthold Sørensen 1931.

60.L. P. Hansen 1932.

61.Balle 1936.

62.Harald Jensen 1936.

63.Johannes Jensen in Harald Jensen 1936, 299.

64.Johannes Jensen 1937.

65.Wistoft et. al. 1991, 273.

66.Harald Jensen 1941.

67.Harald Jensen 1936, 296.

68.Hasselbalch-Larsen 1936, 294; Harald Jensen 1936, 295.

69.Hasselbalch-Larsen 1936, 293.

70.Hasselbalch-Larsen 1937.

71.Jes Christiansen 1937, 406.

72.Johannes Jensen 1946.

73.Harald Jensen 1941.

74.Harald Jensen 1940 and 1951, 286.

75.E.g. Kjærgaard-Jensen 1944, 395 and "Elektricitetsforsyningens rationalisering og mejerierne", *Mælkeritidende* Vol. 59 (1946), 369-370.

76.Danmarks Statistik 1939, table IIIB (nr. 102) and 1953, table IIB (nr. 123).

77.*Randers kommunale elværk* ... (1956), 18.

78.*Dansk Elværksstatistik 1960/61*: pp. 30-31 and *Dansk Elværksstatistik 1965/66*: p. 17-18 [Descriptions of public supply companies]. For arguments for the shift from autoproduction to public supply of the co-operative factory, I am indepted to dir. Jørgen Østerheden and former dir. Ib Fock (DAC).

79.Contrary to the old system, the new pricing system distinguished between morning, afternoon and evening prices. By the way, although its electricity production ceased, the factory maintained the production of steam (as well as its recently reintroduced waste heat technology) for heating pruposes (preheating the oil, factory heating and district heating). For this information I am indepted to Henning Jensen (A/S Aalborg Portland).

Notes to the Conclusion

1.Lucas 1978, 347.
2.Hughes 1983, 461.
3.Bowers 1978, 289-290.
4.Nye 1990, 236-237 and Statistical office of the European Communities 1966, 299.
5.Statistical office of the European Communities 1974, 228-229.
6.Wistoft et. al. 1992, 153-157.
7.This was so in 1950, 1970 and 1990. Wistoft et. al. 1992, 111.
8.Kaijser 1995, 48.
9.Hirsh 1989, 16.
10.Hirsh 1989, 72.
11.Bowers 1978, 286 ff.
12.Kaijser 1995, 33-34, 38-39 and 43-44.
13.See Hesselmans 1995, 115 ff. and Centraal Bureau voor de Statistiek 1941, table I.

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