Martijn Jonker

Modernization of electricity networks

Exploring the interrelations between institutions and technology

38

NEXT GENERATION INFRASTRUCTURES FOUNDATION

TR diss

Stellingen behorende bij het proefschrift

Modernization of electricity networks
Exploring the interrelations between institutions and technology

1. Afstemming (Engels: alignment) van instituties en technologie is een concept noodzakelijk om de modernisering van elektriciteitsnetwerken te begrijpen (dit proefschrift).

2. Om van de meeste dingen in het leven te genieten kun je beter geen kenner zijn.

3. Liberalisering heeft niet radicale innovatie, maar juist incrementele innovatie gestimuleerd (dit proefschrift).

4. Mensen die van dichtbij komen zijn vaker te laat dan mensen die van ver komen.

5. Vanwege de intrinsieke neiging van de elektriciteitssector tot incrementele innovatie in een geliberaliseerde elektriciteitssector dient de overheid alleen bij te springen als ze radicale verandering van elektriciteitsnetwerken wil bevorderen (dit proefschrift).

6. De TU campus is een slechte manier om wetenschap met de maatschappij te verbinden.

7. Modernisering is niet te sturen, maar alleen te faciliteren (dit proefschrift).

8. De beste energie is positieve energie.

9. Het gebruik van het woord 'natuurlijk' als bijwoord (bv. Dit is natuurlijk een goede stelling) sluit alternatieve zienswijzen uit en getuigt daarom van een beperkt blikveld.

10. Plannen is vooral vooruitschuiven.

Deze stellingen zijn verdedigbaar geacht en zijn als zodanig goedgekeurd door de promotor, Prof. dr. J.P.M. Groenewegen.

TD diss

Propositions belonging to the dissertation

Modernization of electricity networks
Exploring the interrelations between institutions and technology

1. Alignment of institutions and technology is a concept necessary to understand the modernisation of electricity networks (this thesis).

2. To enjoy most things in life one better not be a connoisseur.

3. Liberalization did not stimulate radical innovation, but incremental innovation (this thesis).

4. People that come from near are more often late than people that come from far.

5. Due to the intrinsic tendency of the electricity sector to incremental innovation the government in a liberalised sector should only intervene if it wants to stimulate radical change of the electricity networks (this thesis).

6. The TU campus is a bad way to connect science to society.

7. Modernization is not to be steered, but only to be facilitated (this thesis).

8. The best energy is positive energy.

9. The use of the words "of course' (example: This is, of course, a good proposition) excludes alternative perspectives and is therefore considered a limited view.

10. To plan is primarily to postpone.

These propositions are considered opposable and defendable and as such have been approved by the supervisor, Prof. dr. J.P.M. Groenewegen.

Modernization of electricity networks
Exploring the interrelations between institutions and technology

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Preface and acknowledgements

This dissertation is a result of a PhD project which I undertook at the Delft University of Technology at the section Economics of Infrastructures of the faculty Technology, Policy and Management. This research project is part of, and partly funded through, the Next Generation Infrastructures Foundation and is also partly funded by the EDF Foundation. The aim of the thesis is to provide an analysis of the technical and institutional features and their interlinkages that accompany the modernisation of electricity networks.

Although my dissertation is an individual work, I could never have reached the heights or explored the depths without the help, support, guidance and efforts of a lot of people. I would like to express my gratitude to my supervisors Rolf Künneke and John Groenewegen for guiding me through the whole PhD project. The regular meetings I had with them were always very insightful and inspiring to me. Especially towards the end of the project their positive approach and unwavering faith in me always kept me motivated and confident in a prompt and happy ending of the project. Special thanks to Jean-François Auger for his endless stream of helpful advice on my dissertation and on the process of doing research, Aad Correljé and Wolter Lemstra for their comments on my research proposal, Rajen Akalu and Bas Percival for going through the early drafts of the manuscript, and my former roommate Wouter Pieterse for his much appreciated mental support and the keys to the office during occasional weekends. I thank Andrew Barendse, my other former roommate, for his advice on 'doing a PhD' and life in general. I would also like to thank Theo Fens, Peter Spaans, Vic Hayes, Daniel Scholten, Julia Trombetta, Teus van Eck, Henrik Rood, Jan Jaap Bouma, Delphine Françoise, Richard van Gemert, Eeke Mast, Paul Hermans, YJ Park, Peter Anker, Marianne van der Steen and Klara Paardenkooper for their critical and constructive feedback during our weekly section meetings. Moreover, I would like to thank Prisca Koelman for assisting me with the administrative work at the end of the PhD project. In general I want to thank all my colleagues at the section and at the faculty of Technology, Policy and Management for making my stay at university a very pleasant experience.

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Den Haag, September 2010

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Part 1 Introduction to the research

1 Introduction

The electricity sector is in motion. What in most countries once was a monopolistic and relatively stable sector has in recent decades turned into a very dynamic sector. A number of important issues play a role in the dynamism of the current electricity sector, including the following. First, sustainability is an important driver for the change of the electricity system. Small-scale electricity generators, such as wind mills, solar panels and micro combined heat and power facilities are increasingly contributing to a cleaner power production. This poses new demands on the current electricity network that has to be aligned with generation as it needs to become more 'smart' in order to deal with issues like decentralization and intermittancy of the power production (Donkelaar, 2004). Second is the aim of the European Commission for an integrated European electricity market (Jamasb and Pollit, 2005), which demands expansion, or reinforcement, of current interconnectors and networks. This particular network adaptation is also needed to accommodate newly built large scale generation facilities. A third issue refers to the ageing of network components. A vast number of the electricity network assets in place is reaching the end of their technical life cycle. These assets need to be replaced in the coming decades to maintain the current level of reliability of the system. This replacement effort requires major capital investments (Jongepier, 2007). In sum, there is a number of developments that require a substantial technical adaptation of the existing electricity network to meet current needs by expanding, reinforcing, or innovating the system.[1] We refer to this adaptation of technology as modernization.[2] Modernization is needed to guarantee reliability of electricity supply, to enhance the efficiency and productivity of the sector, and to enable innovative services in the electricity sector.

Next to developments in the technical sphere there is a number of important developments in the institutional sphere. Since the past three decades many governments around the world have adopted the liberalization[3] paradigm and have acted accordingly by inserting market mechanisms in the electricity sector (Sioshansi and Pfaffenberger, 2006). However, there is concern that the institutional reform of liberalization has resulted in an electricity sector that lacks sufficient incentives for modernization (WRR, 2008). Apparently the institutions[4] (i.e. the social rules that structure social interactions (Hodgson, 2006)) in place do not adequately stimulate modernization. Fairley (2004) emphasizes the electricity industry's underinvestment in innovative activity. According to Scott (2007: 8), '[t]here is now a consensus of expert opinion that the low level of innovation across the [electricity network] sector needs to be addressed.' The above-mentioned issues suggest that in the process of restructuring institutions provide particular incentives with an impact on the innovation of the technical system. This perspective is inspired by the literature on innovation systems (e.g. Freeman, 1995; Lundvall, 1992; Malerba, 2004) in which the institutions are regarded as an innovation system that influences innovative activity. The influence of the institutions on the innovation of the network seems an important issue in the modernization of electricity networks that needs to be further explored.

However, also the opposite holds, i.e. technology influences the institutions. The electricity system has certain specific technical attributes that affect the institutional arrangements of the system. Joskow (2003) lists a number of these attributes. An example of an important attribute of the standard electricity system is that supply and demand of electricity have to be balanced in real-time in order to avoid any disruptions of the electricity system.[5] According to Joskow (2003: 552), these technical attributes 'affect the design of efficient market and regulatory institutions.' Furthermore, the appropriateness of the institutions in place may change as a result of technical change (Newbery, 2001).[6]

These references suggest an interrelation between institutions and technology.[7] Finger et al. (2005) even go a step further in proposing that the alignment (or 'coherence') between institutions and technology is an important factor to influence the technical performance of the system.[8] For a technical system to perform well it is explained that specific essential functions of the system have to be guaranteed. In other words, when the function is institutionally not safeguarded the system will not function according to expectations. For instance, real time load balancing means that the production and consumption of electric power needs to be technically balanced within very short time periods of seconds or minutes. This technical need has to be supported by appropriate institutions, which is typically done by assigning certain property rights and decision rights to a system operator. If these technical needs are not sufficiently supported by institutions, this results according to Finger et al. (2005) in an unsatisfactory technical performance of the energy system, which might be in the worst case black outs. If this is the case, either institutions or technology have to be adapted in order to meet expectations with respect to the performance of the system. Hence, in this perspective modernization can be considered as a possible consequence of the misalignment between institutions and technology. The nature of this relationship between technology and institutions and how this alignment influences the modernization has not yet been explored.

The aim of this research is to provide theoretical and practical insights into these relationships and to disentangle the concept of modernization of electricity networks. We are interested in both the effects of alignment issues and the influence of institutions on innovation in the electricity sector. This seems to be an important issue to meet the above-mentioned challenges. Solutions could for a large part be found in the modernization of the network[9] and then the question is what drives and hinders modernization? Furthermore, how could industry and government play a supporting role in modernization? Answering these significant questions provides some fresh insights into the governance of next generation electricity networks. An analysis of historical cases seems appropriate to acquire a thorough understanding of electricity networks and to fully appreciate the current challenges the electricity sector is facing. This would contribute to answer the above questions.

The remainder of this chapter is structured as follows. In section 1.1 we provide a brief overview of major physical elements of electricity networks. In section 1.2 we further elaborate on the technical needs for modernization of this system. In section 1.3 we identify different categories of modernization, labeled as innovative and conventional modernization. Subsequently, in section 1.4 we discuss the research focus of the thesis. We elaborate on the research objectives and the framework in section 1.5. We discuss the scientific and practical contributions in sections 1.6 and 1.7. Finally, in section 1.8 we summarize the structure of this dissertation.

1.1 Electricity system[10]

Figure 1 is a representation of the physical electricity system. The electricity system has three distinct functions. First is the function of the production of electricity which can be provided by a coal fired power plant, a nuclear plant, a gas fired power plant, a windmill, etc. Second is the consumption of the electricity, or the load, which refers to the industry, households, etc. who use electricity for lighting, appliances and machines. This brings us to the third function and the focus of this research: the transport of the electrical energy which is fulfilled by the electricity network. A common distinction in electricity networks is between the transmission and the distribution network based on the voltage level they are operated on. In practice, the high voltage lines are classified as transmission lines, whereas the medium and low voltage lines have a distribution function, connecting the transmission lines to the customers (PREGO-6, 2003). In the Netherlands the highest voltage level is the national coupling network of 380 kilo volt (kV) – 220 kV in the north east of the Netherlands – which connects all large scale generation plants in the Netherlands. This high voltage network also connects to the network of Belgium and Germany. At a lower voltage level of 150 kV (110 kV in the north east of the Netherlands) there is the provincial coupling network. Historically these 150 kV networks were the main interconnections of the former provincial electricity companies. Subsequently, there is the 10 kV network, which is also referred to as the city distribution network or the middle voltage (MV) network. This 10 kV voltage level is transformed to a low voltage level (LV), at which level the electrical energy is actually practically used: 230 Volt for households (380 Volt for power current) and 700 Volt for industries.

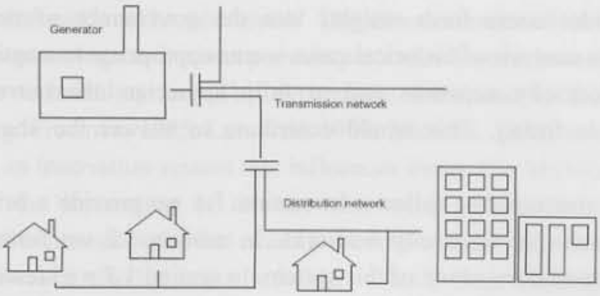

Figure 1 Representation of electricity system

1.2 Need for modernization

A recent global survey of the utilities sector identified the lack of infrastructure investment and the lack of capacity as the most attributable cause of recent issues with regard to security of energy supply (PWC, 2005). The International Energy Agency explicitly calls for modernization of the network with a capital injection of EUR 500 billion in the next 25 years (NRC, 2006). As briefly discussed in the introduction, the need for modernization is induced by a number of trends. There is a trend of increased distributed generation (DG), i.e. small-scale generation facilities, such as wind mills, solar panels and micro combined heat and power (CHP) facilities, which will contribute significantly to a cleaner power production. at the distribution side of the network. According to Borbely and Kreider (2001), the relatively recent direction to distributed generation is the power paradigm for the new millennium. Figure 2 demonstrates the recent shift to more small-scale generators.

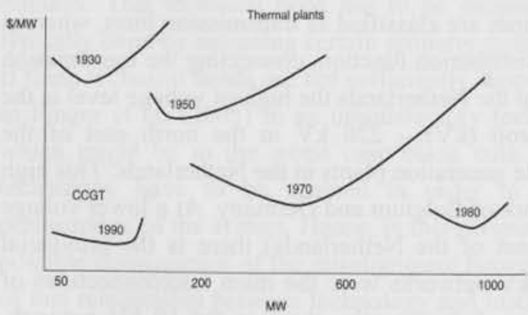

Figure 2 Trends in power generation
Source: Casten (1995)

This figure shows that the costs per installed megawatt (MW) decreased from the 1930s until the 1980s by increasing the scale of the unit. According to this trend generation units were constructed with higher capacities and with larger distances from the load while the networks transported electrical energy with increasingly high voltages. This can be regarded as the economies of scale paradigm. However, in the 1990s we see a disruption as the cost per installed MW is lowered together with the scale of the power generator, as we see from the shift across the horizontal scale. In other words, the trend of distributed generation is opposite to the dominant trend in the last century on economies of scale. A shift to distributed generation encompasses an adaptation of the current network (e.g. Cardell et al., 1998; Lopes et al., 2007). These adaptations can, for example, have the form of new conductors in order to accommodate the increased current flows or new controls in order to influence the behavior of the new current flows. Following Economides' (1996) terminology, distributed generation gradually turns the one-way networks into a two-way network. According to Varming *et al.* (2002: 5) 'future control systems will be called on to handle ever-more-complex problems under increasingly stringent and demanding conditions.' Control of the system can play an important role in distributed generation penetration. Placing new controls in the current networks might, for example, be a way to avoid major investments and make more efficient use of current capacity (Ilic et al., 1998). According to Kundur (2004) the whole network must be operated as a unit closely integrated, i.e. intertwined and interdependent which can be even used more effectively through new technologies such as intelligent systems, on-line security assessment, coordinated emergency controls and real-time system monitoring and control leading to "self healing" systems'. Verbong and Vleuten (2004) see as another possible scenario the emergence of current systems into a integrated European electric super highway system of high voltage lines and cables. There are major generation facilities planned that implicate the strengthening of the current transmission network. This is a continuation of the 'economies of scale' paradigm that has been dominant in the electricity sector in the last century. It also relates to the absolutely and relatively increased interconnection capacity (Figure 3).

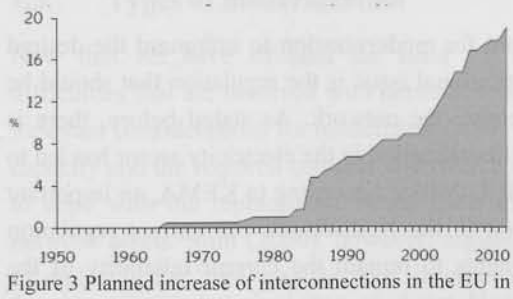

Figure 3 Planned increase of interconnections in the EU in % of installed generation capacity
Source: EU (2000) in The European power grid - the need for regulatory changes and advanced technology by ABB

Another important issue is the ageing of electricity networks that requires a major replacement effort in the coming years to maintain the current level of reliability (see Figure 4). Sector specialists call for substantial capital investment as a way to cope with the aging electricity network assets (NRC, 8 February 2003, NRC, 10 February 2003, PWC, 2005, PWC, 2006; Graves and Baker, 2005; von Hirschhausen et al., 2004). With regard to the Netherlands, we observe that a substantial number of components of electricity networks date from the 1960s and 1970s (PREGO-29, 2005). Smit points out that components of electricity networks last technically on average approximately thirty years (Smit in NRC, 8 February 2002). Assuming such a life time, there is an urgent need for either the replacing or upgrading of components and subsystems.[11] Jongepier (2007) comes to a similar conclusion expecting that within a time horizon of fifteen years the technical performance of the electricity networks will deteriorate significantly. According to Smit, 10% of the Dutch network components already have passed the thirty years life-span and their replacements are urgently needed (see also Figure 4). Moreover, another 40% of the installed components will pass this critical life time in the next ten years and substantial network replacement needs are foreseen (NRC, 8 February 2003).

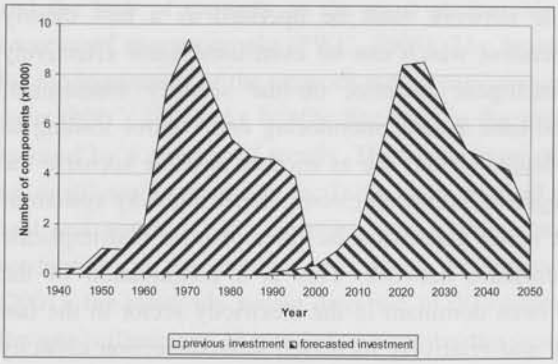

Figure 4 Forecasted electricity network replacement needs
Source: Adapted from NRC (2003)

Various experts acknowledge the current need for modernization to safeguard the desired performance of the networks. A relevant institutional issue is the regulation that should be in place to make network companies modernize the network. As stated before, there is some concern that the institutional reform of liberalization in the electricity sector has led to insufficient incentives for modernization (WRR, 2008). According to KEMA, an important energy research and consultancy organization in the Netherlands, the current regulation does not accommodate the required investments to remain the current reliability of the networks (Figure 5). Current regulation would result in certain investment in network technology that would be accompanied by increasing interruptions compared to the current situation. Investment waves, that are a result of the regulation, explain the downward slope of the line in certain periods.

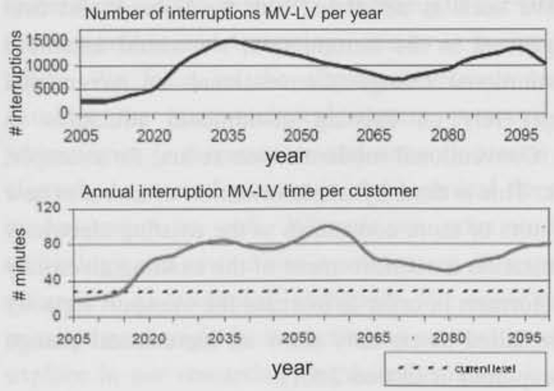

Figure 5 Expected reliability with current regulation
MV: medium voltage, LV: low voltage
Source: KEMA (2006)

This view is supported by existing economic literature that identifies a number of the difficulties accompanying modernization of electricity and other network industries (Dijk, 2001, 2008). In this respect sunk investment, or sunk costs,[12] is an important issue as it points to the irreversibility of the investment in the infrastructure. A second difficulty is the long lead time of infrastructure projects. This refers to the long period between the start and use of the investment. Third, investments in infrastructures are lumpy. In general expansion, renewal and construction of new infrastructure can only take place stepwise. A fourth point is the long life cycle of assets. These aspects emphasize the difficulty involved in the modernization of electricity networks.

1.3 Types of modernization

Now that we have stressed the need for modernization and discussed some of the difficulties that are involved with network modernization we focus on modernization itself. Relevant considerations for modernization are the required type of technology, the required capacity and the required controls with which to modernize the electricity network. In order to cope with the replacement needs some experts urge for investments in conventional network assets. Smit (2006), however, argues that new technologies are necessary instead of replacing the 'like with the like' in order to cope with customer reliance on power, to meet environmental pressures, to comply with decentralization trend and to allow for innovative sustainable solutions e.g. the development of energy storage technology. This brings us to a differentiation of the concept of modernization with (1) conventional technology and (2) innovative technology. We present modernization in two distinct categories to illustrate the difference. We note, however, that the distinction is not always very evident as the extent of innovativeness of a technology is a sliding scale.[13] The issue of investing in technology that is very innovative brings about other issues compared to the use of technology that is little innovative such as additional risk for failures and user acceptance. In addition to what we suggested in the introduction, we would assume a relation between technological and institutional change. Conventional, or incremental innovative modernization might stronger rely on existing institutional structures as compared to innovative modernizations. Conventional modernization refers, for example, to an expansion of the electricity network. This is done by implementation of assets to new locations in order to connect more generators or more consumers to the existing electricity network. Another related form of modernization is reinforcement of the existing electricity system by adding extra lines, cables, transformers in order to increase the transport capacity from one point to another. The newly installed assets only show an incremental change from the already installed assets (further explored in section 2.5.1).

Innovative modernization is acknowledged by a number of scholars (e.g. Voropai and Handschin, 2001; Rabinowitz, 2002; Smit, 2006). Examples in the electricity sector include the shift from direct current (DC) to alternating current (AC) technology in the early days of electricity systems,[14] or the shift from oil pressured cables to XLPE[15] cables which made the electricity system as a whole more reliable (Grotenhuis et al., 1997). Innovative technology, for example, is implemented to increase reliability, reduce visual pollution of electricity poles, etc. and can be characterized as a radical change from existing deployed assets (further explored in section 2.5.1).

1.4 Research focus

In our research we suggest to apply two related perspectives, based on multiple disciplines of economics, sociology and engineering. The first perspective refers to the electricity system as a socio-technical system, a complex system in which technical and social elements are strongly interwoven (e.g. Hughes, 1987).[16] In this view technology is aligned to other technical elements in the bigger structure as well as to the social and organizational elements in the structure (this will be further discussed in Chapter 2). A recent spate of literature focuses on the co-evolution of institutions and technology (e.g. Nelson and Sampat, 2001; Perez, 2002; Tunzelmann, 2003) and builds on the socio-technical system perspective by addressing institutions and technology in a combined manner. This literature builds on the idea that technology can induce institutional change, and oppositely, institutions can induce technical change. An important aspect in this literature is the relationship of both institutions and technology. A related school of thought addresses the alignment (or coherence) of the institutions and technology as a key concept in explaining developments in infrastructure systems (Finger et al., 2005; Künneke, 2008). Central is the issue of aligning institutions and technology in order to guarantee the fulfillment of specific system technical functions, i.e. the functions that are fundamental for the functioning of the infrastructure system, for example real-time balancing in the electricity system. Based on this literature modernization seems to be driven by a need to align the institutions with the technology (and vice versa). According to our first analytical perspective the alignment of the institutions and technology results in a certain technical performance (Finger et al., 2005). We focus on the alignment between technology and institutions, but we also consider the socio-technical system perspective in which separate but connected technologies (e.g. generator and network assets) in a large technical system have to be aligned. Any misalignment in the technical domain may cause friction and can induce modernization as well. Whereas we refer to the previously addressed link between technology and institutions as alignment, this specific link between technologies will be referred to as 'technical' alignment. We argue on the one hand that the system through misalignment might be impacting on network modernization, a relationship that we further explore in our research.[17] On the other hand, it is expected that network modernization might influence the alignment of the existing infrastructure system (see Figure 6).

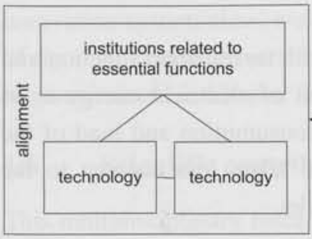

Figure 6 Relation between network modernization and alignment

The second perspective we apply in our research relates to the relationship between the existing institutions in the system and the technical change of electricity components (see Groenewegen, 2005). In this perspective the institutions are considered the variables that explain certain innovations (Figure 7). Innovation is, as stated previously, a specific form or part of modernization next to the conventional modernization (addressed in section 1.3). This perspective is inspired by the literature on national innovation systems (e.g. Freeman, 1995; Lundvall, 1992) and sectoral innovation systems (e.g. Malerba, 2004) in which the institutions are regarded as an innovation system that impacts the innovative activity of the system. This will be further addressed in Chapter 2.

Figure 7 Relation between institutions and network modernization

The institutions in the two perspectives differ conceptually. In perspective 1 we refer to institutions that support essential functions of electricity networks, like for instance contracts between the electricity producer and the transmission system operator to be able to balance the electricity system. In perspective 2 we refer to the institutions that as an innovation system has a certain impact on the innovation. When we analyze for instance the influence of the Dutch institutions on the innovation in the Dutch electricity sector we pay attention to the specific Dutch values, norms, laws, regulations and organizations that together form the Dutch institutional structure. In the literature on National Innovation Systems that relationship is analyzed and the performance in terms of innovations is explained by different institutional structures.

We also note that the two analytical perspectives are two specific lenses with which we explore the reality of the electricity network modernization, Therewith this analysis is - as any analysis - inherently and necessarily a partial analysis a lense to provide us with a focus (see also Groenewegen and Vromen, 1996). We realize that the two lenses show us certain aspects of the electricity network very clearly, while other aspects will remain in the dark. We expect that the two perspectives will highlight those aspects that will provide deeper insight into our questions about the link between technology and institutions and the consequences for modernization and the questions about the innovation system's rol in modernization.

The main focus of this research is on the electricity network with its transport function and its relevant actors in the Netherlands (Figure 8).[18] Generation of electrical energy is an essential element of the whole electricity system, so are the consumption and load of the generated electrical energy. These two important aspects are taken into account to the extent that they relate to modernization of the electricity networks.

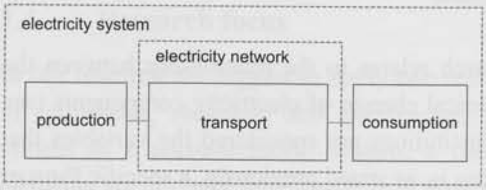

Figure 8 Supply chain of electricity

1.5 Research objective and framework

The objective of this research is to disentangle modernization of electricity networks in the Netherlands. We approach the issue of modernization with two analytical perspectives as discussed above and aim to explain changing technology and institutions of electricity networks as a result of two factors: (1) the alignment of institutions and technology and (2) the innovation system. This leads us to the following research question:

What are important variables in the modernization of electricity networks in the Netherlands from two perspectives: the alignment of institutions and technology, and the innovation system?

It is important to stress that we aim to identify important (relations of) variables in modernization, not in the logical deductive sense in which the causality of variables is assumed,[19] but in a systematic form of storytelling where patterns of relations are the very essence of social reality. This pattern model, as referred to by Kaplan (1964), is constructed by connecting themes in a pattern. 'The event or action is explained by identifying its place in a pattern that characterizes the ongoing processes of change in the whole system' (Wilber and Harrison, 1978: 73). That means that we do not claim to formulate any predictive, lawlike statements, but that our focus is more on understanding the relationships in modernization. In this sense, the word 'variables' in the research question can also be substituted by the words 'patterns' or 'patterns of relationships'.

To assess the variables of modernization from the first perspective a literature review is undertaken. This provides us with an overview of the modernization processes in history and enables us to see if and how alignment of institutions and technology has played a role in these processes. Furthermore, it allows us to understand how modernization has affected the alignment of institutions and technology. With regard to the second perspective, the innovation system view, we conduct interviews and a survey in order to make an inventory of the institutional drivers impacting on innovation. We discuss the research methodology in greater detail in Chapter 3 and 8 respectively.

1.6 Scientific contribution

This multidisciplinary research on technology and institutions adds to the growing body of literature on the co-evolution of institutions and technology and increases our understanding of modernization of electricity networks. The analytical perspective with regard to the alignment of institutions and technology is a relatively young field of research. Analysis in this field contributes to unerstanding the relationships with regard to the alignment of institutions and technology and modernization. For example, we aim to analyze how and under what circumstances a certain alignment between technology and institutions results in modernization. Furthermore, we aim to analyze how modernization affected the alignment of institutions and technology. It provides an additional or alternative perspective on modernization to the more standard approaches from, for example, innovation literature.[20] Additionally, this analytical perspective stresses the need for understanding the previously addressed alignment issues when modernizing the electricity networks. With regard to the second analytical perspective of the innovation system this research could increase our understanding of innovation used to modernize the electricity networks by identifying the important institutional variables impacting on innovation.

1.7 Practical contribution

The practical relevance of this study is to gain insights in the modernization of electricity networks in order 'to keep the lights on'. As almost any economic sector is intertwined with the electricity sector, the dependence on electricity supply is evident. Thus, next to the importance of electricity in our daily life, the modernization of the electricity infrastructure is important for the continuation of the performance of the whole economy. The perspective with regard to the alignment of institutions and technology focuses on both the technical and institutional aspects that are involved in these processes. This approach is important for economists and policy makers who have a tendency of not considering the specificities of the technology in their policy making effort (Jonker, 2009). Many economists focus solely on the market mechanism as an instrument to enhance efficiency and economic welfare therewith ignoring the technical aspect of the system, whereas many engineers are only concerned with the technical system control therewith ignoring any economic or institutional aspect (Künneke and Finger, 2007). Moreover, with the insight in the institutional and technological developments and the technological and institutional drivers involved, we expect to be able to formulate effective policy recommendations for the modernization of the electricity sector. Furthermore, network companies and equipment supplying companies might benefit from a better understanding of the innovation system, i.e. the institutional variables impacting on innovation. A better understanding of these variables can serve as the input for policy makers, i.e. government policy makers and innovation managers in companies, to make technology or innovation policies.

1.8 Structure of the dissertation

Our study falls into four parts: (1) the introduction to the research, (2) the perspective on alignment of technology and institutions, (3) the innovation system view and (4) the synthesis (see Figure 9).

Part 1 concerns the first two chapters of this dissertation. This chapter has given an introduction to the issues related to electricity network modernization and explicates the motivation of the research. Chapter 2 is a literature review, a theoretical exploration. That chapter will discuss literature relevant to the two analytical perspectives of our research.

Chapter 3 is the first chapter of Part 2. That chapter is an introduction which discusses the methodology of the alignment of institutions and technology with respect to modernization. Chapters 4–7 provide us with an insight in the technology, the institutions, their alignment and the modernization in each period we will distinguish from the time of the first electricity network to today. Chapter 8 is the introductory chapter to Part 3 in which the methodology of the second analytical perspective is discussed. Chapter 9 provides us with an inventory of the institutional variables that affected innovation previous to the liberalization of 1998. Chapter 10 elaborates on the variables that affected innovation since the liberalization and provides a comparison with the period prior to liberalization. Chapter 11 provides a synthesis in which the conclusions of Part 2 and 3 are elaborated. Chapter 12 concludes this dissertation with a discussion on the implications and the limitations of this research and suggestions further research.

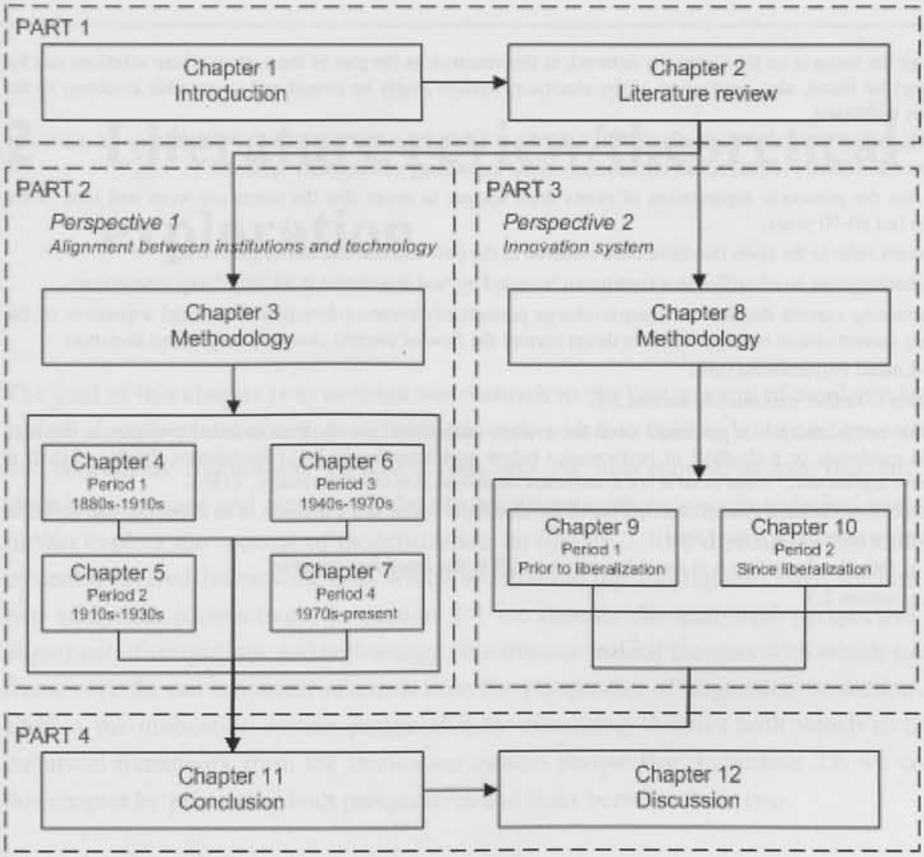

Figure 9 Structure of the dissertation

Notes on Chapter 1

1 However, the desire to make the network suitable for future developments can also be a current need.

2 We will further elaborate on the concept of modernization in the literature review.

3 Liberalization "refers to attempts to introduce competition in some or all segments of the market, and remove barriers to trade and exchange" (Sioshansi and Pfaffenberger, 2006: 41) (also the US' term 'deregulation' is often used for liberalization). Although privatization is named often in combination with liberalization it is not the same. "Privatization generally refers to selling government-owned assets to the private sector, as was done in most countries that embarked on market reform (Sioshansi and Pfaffenberger, 2006: 41).

4 The concept is further explained in section 2.3.

5 We refer to a typical contemporary electricity system with alternating current.

6 For example, if we were to go to a system of direct current – a trend that is present for high voltage international connections – real-time balancing would not be required and this would allow for abolishing the institutions that nowadays safeguard this real-time balancing.

7 Also the technical alignment of the network to the changing generation facilities have been touched upon.

8 Further explained in section 2.4.

[9] Although the focus is on the electricity network in this research as the part of the system where solutions can for a large part be found, also production of the electricity system might be considered as possible solutions to the challenges addressed.

[10] See Hughes (1983) and Patterson (2003) and for a more extensive overview of the history of electricity networks or El-Hawary (2008) for an introduction of the technology of electricity systems.

[11] Note that the economic depreciation of assets does not per se mean that the assets are worn and torn. Some assets can last 60-70 years.

[12] Sunk costs refer to the costs that have been incurred in the past and that can not be recovered.

[13] i.e. technology can be classified in a continuum bounded by 'not innovative at all' and 'very innovative'.

[14] In alternating current the flow of electric charge periodically reverses direction. The usual waveform of the alternating current circuit is a sine wave. In direct current the flow of electric charge is only in one direction.

[15] Cross-Linked Polyethelene cable

[16] This term is further explained in section 2.1.

[17] In other words, there is a perceived need for system adaptation 'mostly from external pressure, a threat to continued existence, or a shortfall of performance below aspiration levels [..]' (Nooteboom, 2000a: 174). It is furthermore argued that, 'while need is not a sufficient condition, it is often necessary.' (186).

[18] For some more detailed system descriptions of the electricity sector and a division in an economic and technical sub system we refer to De Vries (2004).

[19] i.e. if A, then B, where item A is the independent and B is the dependent variable.

[20] See e.g. section 2.5.

2 Literature review/theoretical exploration

The goal of this chapter is to position our research in the vast amount of available literature and to identify useful concepts in literature with which to further build and operationalize the conceptual framework. First we elaborate on important concepts relevant to the electricity network and we present the electricity network as a socio-technical system. We further explore the concept of modernization. In section 2.3 we discuss the institutions and present a layered framework with which to structure the institutions. Then we turn to our two analytical perspectives. In section 2.4 we discuss the analytical perspective of the alignment of institutions and technology. We discuss several theories with which to build a framework for our empirical research from the perspective of alignment. In section 2.5 we address the innovation system perspective by discussing theories with which to build an empirical framework from the innovation system perspective. In section 2.6 we conclude this chapter by presenting both perspectives and links between these two.

2.1 Electricity networks as socio-technical systems

This section provides a short summary of related literature that addresses significant features of electricity networks that will be addressed in our empirical research. Some important technical aspects of networks are related to its artefacts and topology. The perspective of Complex Products and Systems conceptualizes electricity systems at the level of artefacts. Its focus is the complex system of the electricity network, which can be understood as a technical hierarchy, consisting of materials, components, devices and subsystems. This view has a strong focus on the technical components of electricity networks such as transformers, wires, cables and switches. In electricity systems the structure, or network topology, is an important characteristic (Sahal, 1993). For assessing the structure of these networks and their development, we rely on the network topologies as proposed by scholars like Barabási (2003) and Newman (2003). Important concepts include central, distributed, density, number of cycles, types of network and directions of flows. Where the above mentioned scholars perspective is on the electricity system as a number of technical components with a certain structure, we broaden this perspective by including the social and organizational elements (and their relation with the technology) as these are considered as crucial and integral parts of the system in determining its perfomance (Kroes et al., 2006). By doing so, electricity networks are referred to as socio-technical systems and conceived as complex systems in which technical and social elements are strongly interwoven (Hughes, 1987). This perspective is in the tradition of large technical systems (further discussed in section 2.4.1) and transition theory (further discussed in section 2.4.2), both approaches in the subdiscipline in the history of science and technology. Some of the technological, economic and policy aspects of electricity networks can be illustrated by identifying different levels of analysis. In this respect a useful distinction made in electricity networks is that of primary and secondary infrastructure. Primary infrastructure refers to the basic physical elements of the electricity networks, such as wires, switches and transformers with a prime function to transport electrical energy from A to B. This infrastructure level is also referred to as the physical facilities, whether at the level of links and nodes in the network or at the level of their components (Weijnen and Bouwmans, 2006). Another level of infrastructure is the level of management and control, concerned with new control engineering concepts (Weijnen and Bouwmans, 2006).[1] This level relates to the secondary infrastructure: the information system or the intelligence of the system. The information system/intelligence of the system is an important aspect for the management control of the infrastructure. This management and control concept is part of a social network concerned with the infrastructure system. Weijnen and Bouwmans (2006: 124) analytically add this social network to the physical network as described above stressing that an infrastructure should be regarded as

> a highly complex networked system, which includes both a physical and a social network. The behaviour of an infrastructure cannot be understood by merely looking at the structure and dynamic behaviour of either the physical or the social network. Both are interconnected and interwoven in many ways. The social and economic value of the infrastructure is only determined by the service it provides to its end users. The quality and reliability of that service, in turn, are determined by the performance of the integrated system, i.e., the integrated physical and social network. Both networks are complex in themselves – and their interaction, at the level of the integrated socio-technical system, presents another domain of complexity.

The quality and reliability of the service brings us to another attribute of the infrastructure: the service characteristics. Saviotti (1996) distinguishes in his so-called twin characteristics framework between technical and service characteristics of technology, where the technical aspects refer to the internal structural aspects of the system and the service characteristics refer to the broader external functional aspects of the system. We follow this distinction in conceptualizing the electricity system. The technical characteristics have been discussed above as the perspectives of Complex Products and Systems and Network Topology. The service characteristics can be divided in (1) technical performance and (2) economic performance.[2] Technical performance refers to quality of electricity supply, a concept that is divided in three dimensions: (1) reliability, (2) power quality and (3) commercial quality.[3] Some scholars make a distinction between basic service and value added services. The first two dimensions refer to the basic service, the third to the value added services. First, reliability is a general term encompassing all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilization within acceptable standards and in the amounts desired. Power system reliability, comprising of generation and transmission facilities, can be described by two basic and functional attributes: adequacy and security.[4] Second, power quality covers a variety of disturbances in an electricity network system. It is mainly determined by the physical quality of the sinusoidal voltage waveform. The relevant technical phenomena are variations in frequency, fluctuations in voltage magnitude and waveform distortion. Third, next to the physical supply of electricity, the network company has a commercial relation with its customers. Examples are the connection of new customers, the invoice or the reply to questions or complaints. We conclude that there are several ways to conceptualize electricity networks. As the technical system perspective does not fully cover the performance (or service characteristics) of the system we conceptualize the electricity system as a socio-technical system in which the technical and social elements are strongly interwoven.

2.2 Modernization

Modernization is 'the action or an act of modernizing something; the state of being modernized' (Oxford English Dictionary (OED)). According to the OED, to *modernise* is

> to make modern, to bring up to date; to give a modern character or appearance to; to adapt to modern needs or habits; (sometimes) spec. (a) to rewrite (an old text) in modern spelling or language; to change (obsolete spelling, words, or language) for modern equivalents; (b) to remodel and refashion (an old building) in a modern style; to provide (a house, business, etc.) with modern conveniences or equipment.

Other uses, with regard to variations of the term modernization, can be found within different fields. For example, modernism is a cultural movement that generally includes the progressive art and architecture, music, literature and design which emerged in the decades before 1914. Furthermore, there are modernization theories from sociology that have been developed and popularized in the 1950s and 1960s. A notable recent use of modernization as a concept is by Paul Edwards (2002: 185) who argues that infrastructures such as the electricity system are 'the connective tissue and the circulatory systems of modernity'. His concept of modernization relates to society as a whole with a distinctive role for infrastructures to accommodate this 'societal modernization'. The term modernization can also be understood as an engineering concept. Modernization of the network then relates to the implementation of technology to an existing system. This can be either done by (a) addition of a component to the network or by (b) substitution of a component. This distinction is common among network operators (see e.g. Annual report Continuon, 2004:

11). Substitution of a component is the dissolution of one component of the electricity network and the simultaneous deposition of another in its place. This view is strongly related to substitution approaches which understand technological transitions as a replacement process in which new technology substitutes existing ones (e.g. Nakićenović, 1986; Grübler 1991, 1998 and Farell, 1993). This is typically referred to as *competition* of technologies. "Substitution of a component," according to Geels (2005: 33) "may have wider cascade dynamics in the entire artefact [the network]. Changes may thus cascade from lower to higher levels in the technical hierarchy." However, according to Pistorius and Utterback (1997: 68), "there are many cases where technologies interact in a relationship that is confrontational and where the interaction between technologies is not one of competition in the strict sense of the word." It is often referred to as *symbiosis* or the addition of components. This holds in cases where two technologies have positive reciprocal effects on one another's growth rate.[5] The process of addition of components is typically described by S-curves (see e.g. Pistorius and Utterback, 1997; Geels, 2005).

In this thesis we perceive modernization as a purposeful process of adapting the electricity network to current and future needs by implementing technology into the network which has a result on its performance. In our research we consider modernization as technical change of the system. By excluding analytically the concept of institutional change from the concept of modernization we conceptually distinguish between modernization and institutional change. As previously discussed (section 1.3) this implemented technology can be classified as conventional (incremental) and innovative (radical) (see also section 2.5.1). We, furthermore, find that modernization can take the form of addition to and substitution of elements to the existing electricity system. Elements might, for example, be added to raise its overall capacity or to increase its redundancy by having extra elements in the system that are used for back up in case of failure of elements. Expansion might be needed to cope with future demand. The extra transport capacity can increase the liquidity of the electricity and hence improve competition or to improve the security of the system, as less congestion might occur.[6]

2.3 Institutions

Recent years have shown a renewed interest in institutions as factors that shape the economic performance of network industries. Hence, a major part of the recent literature on infrastructures builds on the rich tradition in the field of institutional economics.[7] Institutional economics plays a major role in describing the institutional arrangements of network industries such as the electricity sector. These institutional arrangements with regard to electricity networks and the change of these arrangements as a result of liberalization have been the subject of many recent publications (see e.g. Joskow, 2003, 2005; Newbery, 2001; Glachant, 2002; Jamasb and Pollitt, 2001). The field of institutional economics is often divided into the so-called Original Institutional Economics (OIE) and the New Institutional Economics (NIE). In institutional economics, institutions – described as 'durable systems of established and embedded social rules that structure social interactions' (Hodgson, 2006: 13) – play an important role in explaining the performance of the economy. In most of the frameworks of institutional economics layers of institutions are distinguished, in which values and norms, laws and regulations as well as public and private organizations are located (see e.g. Figure 10 of Koppenjan and Groenewegen). As "mechanisms of social interaction", institutions are manifest in, formal organizations such as the national parliament, the national bank and the Roman Catholic Church as well as in the informal social order of culture, habits and customs.

In the explanation of institutions we can find roughly two approaches: institutions emerge and develop 'spontaneously' out of the (un) intended actions at the micro level of actors in the system opposed to the view that institutions are the result of purposeful design both at the individual and the collective level in the system. Moreover, the literature of institutional economics shows explanations of institutions that are based on efficiency (institutions evolve or are designed because they reduce for instance transaction costs), as well as explanations that are based on power structures and the protection of vested interests in the system. The former are related to NIE and the latter to OIE. According to NIE institutions exist because of positive transaction costs, a concept introduced by Ronald Coase in 1937 in his seminal work *The Nature of the Firm*. Reasoning on transaction cost became most widely known through Williamson's *Transaction Cost Economics*. Transaction costs are the costs incurred in coordinating an economic transaction. Examples of transaction costs are the costs involved in searching the required good on the market, finding the seller with the lowest price, checking the qualities of the product, etc. Other examples of transaction costs are related to the negotiation and making of the contracts as well as the cost involved in monitoring and enforcing the contract. Wallis and North (1986) have demonstrated that transaction costs can then become substantial if the institutions that provide the actors in the system with the rules of the game' are not well in place. Next to transaction costs other explanations are provided of why institutions are created, why they differ depending on the specific context of countries and sectors and why they evolve over time in different ways. Especially the insights of OIE are important to understand the variety of institutions and their different dynamics. For more detailed discussions on these issues we refer to Hodgson, 1988, Rutherford, 1994, Vatn, 2005, Groenewegen, 2000, 2005 and Greif, 2006. With respect to our own research we underline the importance of both the NIE and OIE concerning the insights provided in the role of efficiency as well as vested interests, in selection by competition as well as the dynamics of path dependency.

2.3.1 Layered approach

Inspired by the three- and four-layer models of Williamson (1979; 1998) Koppenjan and Groenewegen (2005) propose four layers to frame institutions in socio-technical systems

(Figure 10). In layer 1 the actors and their strategies (games) in socio-technical systems are presented. In the other layers the institutions are shown which on the one hand constrain the actors and on the other hand enable the actors. Moreover, institutions can be both purposefully created by actors and can be the result of a 'spontaneous' evolutionary process. The actors can be individuals but also organizations like firms or ministries. In case of the latter it can be important to include in the analysis of the actor also its internal structure: "Individual agents like firms and households consist of an internal structure that coordinates transactions inside their hierarchy; also inside hierarchies, markets with contracts and transfer prices exist as well as organization-like arrangements [...]' (Koppenjan and Groenewegen, 2005: 246). Hodgson (2006: 10) states that 'there are multiple levels, in which organizations provide institutional rules for individuals, and possibly in turn these organizations can also be treated as actors within broader institutional frameworks.' The first category is where the institutions relate to the organization and the organization can be treated as actors. This analytical abstraction helps us to observe the overall socio-economic change, rather than the internal structure of organizations. The second category focuses more on the internal structure of organizations. In this case, the structure of the organisation and the organisational rules relates to the institutions and the individuals relate to the actors. In other words, there are (1) the institutions that relate to the actor and (2) the institutions internal of the actor that guide its behavior. In cases where the outcomes of behaviour of organizations cannot be fully explained by the 'external' institutions, i.e. the institutions seem actor sensitive (see Hodgson, 2006). We stres that the link between institutions and the actor's behaviour with regard to modernization is 'all but unanimous' (von Hirschhausen et al., 2004: 204).

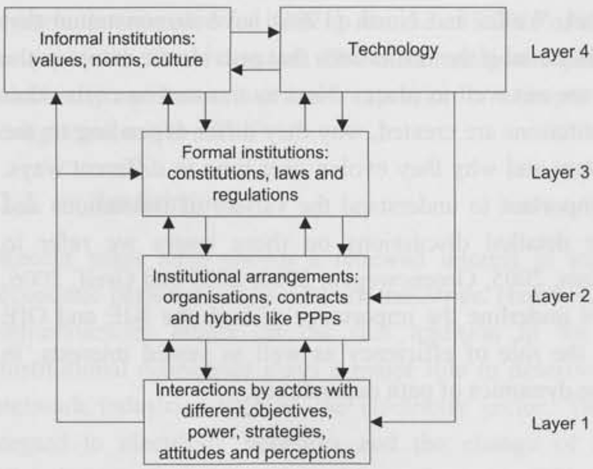

Figure 10 Dynamic layer model of technological, socio-economic systems
Source: Groenewegen (2005) (adapted from Koppenjan and Groenewegen, 2005)

When modeling the actors in a socio-technical system two characteristics are crucial: one about the rationality and the other about the rules of behavior. In the NIE one would typically find approaches in which actors are (bounded) rational and subject to the rule to establish cost minimizing solutions, whereas in OIE one would find also attention to so-called 'situational rationality" and behavior that aims at protecting vested interests. In the latter the interaction between actors and their institutional environment (creating a specific type of situational rationality) is much more important than in NIE. Likewise, in OIE one would find much more attention to power and protection of vested interests then in NIE.

The institutions are positioned in the layers above the actors: first at layer 2 the so-called institutional arrangements.

> At this level of analysis, agents in networks design mechanisms to coordinate the transactions between them. Institutional arrangements, often called 'governance structures', are designed to coordinate specific transactions among multiple actors concerning labour, capital, intermediate goods, information and the like. Next to spot market contracting actors use long-term contracts, subcontracting, forms of 'comakership', joint ventures, strategic alliances, cartels and vertically integrated hierarchies, to name the most important ones [...]. At network level, agents also create arrangements that facilitate the functioning of the network such as business associations, intergovernmental networks and public-private arrangements (Koppenjan and Groenewegen, 2005: 246).

Layers 3 and 4 are often called the 'institutional environment' (North, 1990; Williamson, 1998), indicating that the formal and informal rules of the game are the environment in which the actors are embedded. In the formal part it is about explicit institutions that are written down such as laws and regulations (corporate law and competition law, but also formal rules agreed upon by the private actors such as the rules of arbitrage). In the informal part it is about values, norms and codes that are not explicitly written down, but are present in the minds of the actors. It refers to the shared mental models and ideologies of the actors (Denzau and North, 1994). "This level influences the perceptions of agents with respect to the problems they identify and the solutions they consider feasible. It determines what kinds of incentive structures are acceptable and what would be effective [...]'. (Koppenjan and Groenewegen, 2005: 246).

In Figure 10 the layers are interdependent, which is different from the presentations in the NIE (see Williamson, 1998). The two-sided arrows demonstrate the constraining as well as the enabling and constructing aspect of institutions. In terms of the agent-structure debate in social science (Giddens, 1984) it means that the approach showed in Figure 10 is neither methodologically individualistic nor collectivistic (Hodgson, 2006), but of a methodological interactionistic nature (Groenewegen et al., 2010). That is to say, actors are first moulded by their environment in their rationality and options to design. As Hodgson states, '[..] individuals do not simply (intentionally or unintentionally) create institutions. Through 'reconstructive downward causation' institutions affect individuals in fundamental ways.' (2000: 318). This is also emphasized by Bowles (1998) who focuses on the impact

of the economic institutions on the values, tastes and personalities of the individuals and therewith endogenizes their preferences.
Second, the feed back arrows in Figure 10 show that actors create institutions. Sometimes the analysis will show a large 'latitude of choice' for the actors (i.e. institutions are not very constraining), but in other situations the actors have hardly any room to manoeuver because the technology or the institutional structures (including the market structures) determine and leave no options to the actors. Note that the degree of design differs significantly between the layers of Figure 10 (e.g. norms can not be designed and implemented as regulations). Note also that the time involved greatly differs (e.g. contracts and organizations are implemented at much shorter time notice than laws). Finally note that research on the dynamics of institutions demonstrates a large difference between institutions that are intentionally designed at individual or collective level like laws and regulations and the institutions that result from human behavior, but are not intentionally designed as such (e.g. values and norms.).
The framework presented in Figure 10 will serve as a means to structure the many actors and institutions that we will encounter in our empirical research. The framework allows us to identify different private and public actors that will implement different strategies in different environments. The framework also allows for analyzing behavior both aiming at improving efficiency and at protecting vested interests. Based on the framework we will identify the collective aspects of the environment that create a specific 'mind set' of the actors and we will analyze how those cultural elements changed over time.

2.3.2 Logic of the system

With respect to analyzing the dynamics of the layers and the system as a whole, the framework offers the opportunity to identify a certain 'logic' of the system, which refers to the extent that the four institutional layers are complementary in shaping the institutional system. 'The logic of the system is assumed to be strong if the values, formal rules and governance structures fit well together (Groenewegen and Künneke, 2005: 13).' Using the layers in a dynamic way therewith taking into account the interrelationships of the institutions at different layers would also allow for finding the origin of institutional change and to asssess how the institutional change at one layer influences the institutions at other layers.

2.4 Alignment perspective

It has become widely accepted that technology and institutions are important factors determining the performance of infrastructures. A significant trend in literature on technological innovation and industry emergence during the last 20-25 years has been the view of technical and institutional change as co-evolving (Van de Ven and Hargrave, 2003;

Künneke, 2008). Several theoretical schools have to some extent made explicit this co-evolving nature of infrastructure systems.

2.4.1 Large technical systems

The Large Technical Systems (LTS) approach addresses the evolution of network systems (see e.g. Hughes, 1983; Mayntz and Hughes, 1988; Bijker et al., 1989; La Porte, 1991; Summerton, 1994). Some of the major contributions to this approach, which is part of the school of history of science and technology, are dealing with the evolution of electricity systems. Joerges (1998: 24) defines large technical systems as "complex and heterogeneous systems of physical structure and complex machinery which (1) are materially integrated, or 'coupled' over large spans of space and time [...] and (2) support or sustain the functioning of very large numbers of other technical systems". In the development of these complex systems its interconnected and complementary elements need to adapt to the changing needs. Typically not all elements adapt in the same pace. Hence, some of them might lack behind, which has consequences for the entire system. Hughes (1987) describes this as reverse salients, i.e. frictions in specific parts of the system that hinder its further adaptation. In order to resolve these barriers, innovation activities will be concentrated at these points (Hughes, 1987). Innovations in such networks or infrastructural systems are to be technically aligned with the surrounding structure and hence tend to be incremental in nature. Existing products and technologies undergo processes of slight, continuous improvement rather than radical change. The LTS approach deals with the high degree of stability and inertia of complex network systems. This problem is closely related to the fact that '[i]n many cases, we have to do with the existing infrastructures. Most of the established systems, capital intensive as they are, and embedded in the economic and spatial structure, are slow in responding to changing economic conditions and changing user demands.' (Weijnen and Bouwmans, 2006: 129). Recent literature in this field addresses controls or control systems that are 'used to coordinate the flow of goods, traffic, materials, funds, services or information through complex supply, production or distribution systems […], which can significantly improve the allocation of system traffic, which in turn can increase capacity utilization and enhance system performance.' (Nightingale et al., 2003: 477–478). In this case system modernization is related to improving the control of the technical system. Among others, Lehtonen and Nye (2009) identify information technology (IT) as an important enabler for the liberalization of electricity systems. For the development of decentralized electricity networks, such as smart grids, more advanced controls are needed.[8] In this respect the control aspect of the socio-technical system might be perceived as reverse salients in the above-mentioned sense. Government policy might be instrumental to promote these developments. However, there is little general understanding how this might be accomplished. The above-mentioned authors refer in a case study to the different national styles of regulation for the cases of

Denmark and the UK. This literature is quite helpful to further specify some features of electricity networks as socio-technical systems. However, the analysis remains on a quite abstract level and hence needs further operationalization. With regard to the applicability of the LTS approach in our research we argue that it provides useful concepts. The approach of LTS, however, focuses mainly on the emergence and the stabilization of systems with a certain momentum, instead of overcoming this momentum and bringing about transformations (Geels, 2007). Understanding this transformation is particularly relevant for our research as we aim to understand the modernization of existing systems, thus the transformation from an existing system to a modernized system. Although we are aware of the analytical distinction between changes within the system and changes of the system, we consider the changes of the system as the transformation process with which to arrive at a change of the system. Transition theory aims to provide a conceptual framework with which to understand these transformation processes.

2.4.2 Transition theory

Transition theory aims to understand transitions from one socio-technical system (or 'regime') to another (e.g. Kemp et al., 2001; Kemp et al., 2003; Geels, 2002, 2004; Verbong and Geels, 2007). Transitions typically are long term processes that take at least one generation, i.e. 25-50 years. Furthermore, it needs a number of relevant actors or stakeholders to bring about the long term changes at a systemic level referred to as transitions (Rotmans, 2003). Transition processes are analyzed from a multi-level perspective: technological niches, socio-technical regime and technological landscape. According to transition theory radical novelties usually emerge in the mico-level niches which are initially isolated from the incumbent socio-technical regime. At a macro level the socio-technical landscape is identified. This refers to a usually slowly evolving environment beyond control of the niche and regime actors and refers to concepts as cultural patterns and macro-political developments (Geels and Schot, 2007). Smith et al. (2005: 1491) introduce four 'differentiated transition contexts that determine the form and direction of the regime change'. These contexts are based on the *locus of resources*, i.e. the degree to which the regime is able to respond to selection pressures in the regime itself or outside the regime, and *the coordination of actors*, i.e. the extent to which change is envisaged and actively coordinated. This results in four stylized ideal types: (1) *Endogenous renewal* is a coordinated response by regime actors who internally adapt to perceived pressures. 'Looking back over a long period of time, the transformation can appear radical, but it will have come about through an alignment of smaller changes shaped by existing capabilities and guided by prevailing expectations' (Smith et al., 2005: 1500). (2) *Re-orientation of trajectories* refers to an uncoordinated response of regime actors, using internal resources. This is the result of a shock that occurs in or outside of the current regime. (3) *Emergent transformation* is the uncoordinated pressure of change by regime actors based on capabilities and resources outside the incumbent regime. This source of innovation is related to universities and small and new firms. (4) *Purposive transitions* is the coordinated response of actors with external sources. A prime example of this transition context is the history of civil nuclear power. Although most previous transition literature gives a key role to non-state actors, this example suggests that the coordination of the many diverse resources involved in this transition will in certain circumstances require considerable intervention by states.

Transition theory highlights important aspects in the transformation of systems. The multi-levels and the context of these multi-levels provide us with a good insight in the important variables to change. The levels that are used in transition theory have some commonalities to the layers that were presented in section 2.3 with regard to the institutional framework. The landscape level in transition theory relates to the level of informal institutions where change is typically slow. The lower levels in the model relate to more operational concepts typically changing at a faster pace. Regarding the applicability of the alignment issue we argue that the focus of transition theory is on the change of the socio-technical regime with no explicit distinction between changes in the institutional and technical sphere, a distinction which is essential in our research. In order to get an understanding on both the institutions and technology of development processes of electricity systems we explore theories on the co-evolution of institutions and technology.

2.4.3 Co-evolution of institutions and technology

A number of scholars make an explicit distinction between the institutions and the technology when referring to the development of large technical systems such as electricity systems. To these scholars the institutional and technological variables are considered of utmost importance in the shaping of economic performance. For example, North (1990: 103) argues that '[…] technological change and institutional change are the basic keys to societal and economic evolution […]'. In addition, Nelson and Sampat (2001) distinguish between social technologies and physical technologies referring to institutions and technology respectively. Like North, Nelson and Sampat consider the social technologies to be 'formed, and held in place, in the context of the broad system of norms, beliefs, and rules of the game' (2001: 41). According to them, '[…] it probably is useful to think of physical and social technologies as co-evolving' (p. 51). In this co-evolving process, institutions and physical technologies are acknowledged as constraints as well as productive pathways. Nelson and Nelson (2002: 269) state that

> new social technologies, new "institutions", often come into the picture as changes in the modes of interaction—new ways of organizing work, new kinds of markets, new laws, new forms of collective action—that are called for as the new technologies are brought into economic use. In turn, the institutional structure at any time has a profound effect on, and reflects, the technologies that are in use, and which are being developed.

In other words, technology can induce institutional change and vice versa, which is referred to as co-evolution. The co-evolutionary aspect of technology and institutions or the reciprocal evolutionary change implies that both the domain of institutions and technology can act as a selection environment towards each other (Gilsing and Nooteboom, 2004). On one hand, the institutions determine the technology and on the other hand the technology determines which are the suitable institutions. In Tunzelmann's words: 'Co-evolution implies that the industrial evolution along the path of technology creation and application aligns in some fashion with the governance evolution [...]' (2003: 379). He, furthermore, argues that the way that these two align is far from fully understood and therewith calls for an explanation of the co-evolution of governance and technology. Perez (2002) describes this relation by analytically connecting the techno-economic to the socio-institutional sphere in her description on major technological revolutions and its regularities. She delineates five technological revolutions and describes the relationships between the financial institutions with the phases of the technical revolution. According to her, there is an increasing mismatch between these two spheres, which corresponds to the misalignment of institutions and technology, in the first decade of installation of the new large technical system. Misalignment is expected to be followed by realignment of the institutions and the technology. However, 'the process of re-establishing a good match [...] is complex, protracted and painful.' (p. xvii). Although Perez' approach of matching the institutions and the technology clearly relates to our alignment approach, she is more focused on the technological maturity and market saturation of the technology than of the actual performance of the technology as a result of the alignment of institutions and technology. A link with the performance and the evolution of coordination mechanisms and technology can be found in Nightingale et al. (2003). They link the evolution of large technical systems with a need for more controls that coordinate the technical system in order to arrive at the desired performance of the system. The institutional coordination can be taken over by technical controls in order to increase capacity utilization and therewith increase the overall economic performance of the system. They argue that 'innovations in control technologies and techniques that improve systems coordination are [...] important factors in improving system performance.' (p. 477). Despite the lack of an explicit focus on the institutions of the system, this view highlights the link between the technology of the LTS and the coordination mechanisms as an alignment that leads to a certain performance. In case of a (foreseen) bad performance the system is adapted by technical change, which we refer to as modernization, or by institutional change.

A number of the above-mentioned scholars makes an explicit distinction of institutions[9] and technology and stresses the need for a co-evolutionary approach. Furthermore, in order to understand the specifics of the alignment of institutions and technology we turn to a branch of co-evolution theory that focuses specifically on alignment of the institutions and technology in infrastructure systems.

2.4.4 Coherence between institutions and technology

Finger et al. (2005) specify the issue of co-evolution between institutions and technology with respect to so-called essential functions, and are also referred to as the technical or critical functions in this study. These functions are related to processes in infrastructures that need to be performed in order to safeguard the *technical* functioning of the system. In the most extreme case the infrastructure system might technically fail, if these functions are not properly accommodated technically as well as institutionally. An example is load balancing in electricity systems. The production and consumption of electricity need to be balanced, otherwise, in most extreme cases, the electricity system suffers major black outs. Load balancing is related to certain technical activities, like adjusting the power production to the fluctuating demand. Typically a system operator, like Tennet in The Netherlands, is appointed by law to perform these activities. The system operator has the authority to perform certain tasks within the electricity system in order to safeguard its technical functioning. Hence, essential functions can only be safeguarded if necessary technological tasks are supported by suitable institutional arrangements. Finger et al. (2005) describe this type of alignment as 'coherence between institutions and technology'. The argument is summarized in Figure 11.

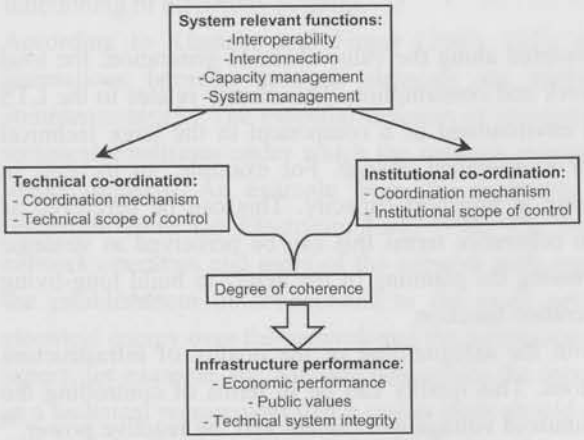

Figure 11 Relationship between technology, institutions, and performance of infrastructures
Source: Finger et al. (2005)

Finger et al. (2005) specify four essential functions, also referred to as the critical technical functions and the system relevant functions: capacity management, system management, interoperability and interconnection. Capacity management is a very sensitive task in infrastructure systems since the scarce network resources need to be allocated between different users and applications. Depending on the time scale on which this capacity allocation occurs, different aspects can be distinguished: real-time operational, tactical and long term strategic. Kunneke and Finger (2007: 310) describe these capacity management functions as follows.

> *Operational real time capacity management* encompasses the continuous technical balancing of the electricity system. This includes automated protection of system elements in case of malfunctioning, certain routines for disturbance response like the adjustment of generation and breakers, and regulation and voltage control. *Tactical capacity management* deals with the allocation of existing resources in order to meet the expected demand. Electricity suppliers have to secure sufficient production capacity in order to meet the contracted demand. Typically they commit generation capacity to the system operator, usually 24 hours in advance for a period of 30 minutes. But also longer time periods, for instance a week ahead, are possible. The system operator is than able to calculate whether the committed capacity is sufficient to meet the expected demand, and whether the system is physically able to support the intended transactions. Another typical aspect of tactical capacity planning is maintenance scheduling. Generation plants need periodical check-ups and repair in order to secure their proper functioning. Especially for larger plants, these outage times are significant and they influence the availability of the production capacity, which might have negative consequences for the system's reliability. *Strategic long-term capacity management* addresses the planning of the newly to build long-living components like for instance the generation plants. Another aspect of long-term planning is the choice for certain generation technologies (like nuclear, fossil, or renewable), and securing the availability of important inputs like primary energy. The reliability of the electricity system can be increased by a certain diversity of technologies that rely on different primary energy sources. Also the planning of new network capacity fits into this category (italics added).

Capacity management should be considered along the value chain of generation, the total power system as generation, the network and consumption. This clearly relates to the LTS literature in which the technological environment of a component in the large technical system can be a driver and a barrier to technical change. For example, an increase in generation capacity induces an increase in transport capacity. This can be percieved as technical alignment of the system. In coherence terms this can be perceived as strategic long-term capacity management addressing the planning of the newly to build long-living components of the network to the generation function.

System management is concerned with the safeguarding of the quality of infrastructure services according to client expectations. This quality can be in terms of controlling the frequency, voltage, the shape of the sinusoid voltage and current and the reactive power.[10] These issues are strongly related to what in the electricity sector are called ancillary services. Ancillary services can be defined as support services to guarantee the quality, reliability and security of the electricity grid (see Appendix A for an inventory). Furthermore, these issues are strongly related to the capacity management. For example, in case of bad capacity management the demand of electricity might exceed the supply of electricity. This subsequently may lower the frequency of the system to a certain extent. The system management function has overlap with the capacity management function to such an extent that it can be fully attributed to the capacity management function of the system. Hence, we omit this system management function in our research as it was omitted in recent coherence literature (see e.g. Künneke and Finger, 2007) and use capacity management, interconnectivity and interoperability as the critical functions for our research.[11]

The essential function of interconnection refers to the physical linkages of separate networks that perform similar or complementary tasks (e.g. Economides, 1996). Interconnection is a constituting feature as infrastructure systems are established by physical networks. A growing degree of interconnection is associated to network externalities – the positive or negative effects on a user of a service or product as a result of others using the same or compatible service or product – since consumers can take profit from extended or improved services (Katz and Shapiro, 1985). In the case of electricity, for instance, system reliability and security of supply increases. This interconnection is not only a technical matter of connecting wires, but also involves important institutional support. For example, technical specifications need to meet certain norms and standards. Besides, the property rights and decision rights with respect to the interconnecting facilities need to be defined and effectuated. For instance, under what circumstances are neighboring countries allowed calling on the reserve capacity[12] of the Dutch electricity system, and vice versa? How to deal with non-controllable loop flows between different parts of the network? These issues need to be resolved in order to support the expected technical functioning of electricity systems.

According to Künneke and Finger (2007: 312) 'interoperability is realized if mutual interactions between network elements are enabled in order to facilitate systems' complementarity.' The essential function of interoperability refers to the institutional and technical conditions under which the network industry, in our case the electricity system, works properly. An example from the electricity sector is the Netcode, a technical regulation from the Electricity Law 1998. The Netcode dictates the behavior for the network operators and users of the network with regard to the operation of the networks, the establishment of connections to the main network, the execution of transport of electrical energy over the network and the international transports.[13] With regard to the first aspect, for example, the Netcode determines the specific bandwidth of the frequency level as a technical requirement that a power plant should operate within in order to support the technical functioning of the whole electricity system.

As indicated in Figure 11 these essential functions need to be supported by institutions and technology. Finger et al. (2005) further specify this in terms of the technical and institutional coordination related to these functions. Coordination relates to two aspects, i.e. the coordination mechanism and the scope of control. Three elementary coordination mechanisms are identified: centralized, decentralized, and peer-to-peer. In the case of centralized coordination, systems activities are determined in a top-down manner. This is the case of a hierarchically organized system in which important functions are performed by selected elements. An example of centralized technical coordination is the above mentioned load balancing. A corresponding institutional example is the planned economy, which was applied in the electricity sector prior to the liberalization. In the case of peer-to-peer coordination, all system elements are fundamentally of equal importance and perform similar functions (see also Thompson et al., 1991 and Powell, 1990). There are no straightforward examples for this in the electricity sector. Certain parts of the Internet are organized in this way. In the Internet for instance, peer-to-peer agreements are established for the mutual exchange of electronic traffic. As an example of peer-to-peer coordination, we mention the filesharing systems through the internet in which all voluntary and interconnected computers are mobilized to share files (documents, audiofiles, or audiovisual materials) amongst all participating systems (Bauwens, 2005). Decentralized coordination relates to a situation in which important system functions are performed in a decentralized matter, typically very close to the location where they are needed. In the case of a strong decentralized electricity production, some of the above mentioned essential functions, like load management, could be performed close to the final consumer.

The scope of control is very much related to the technical and institutional boundaries of the electricity system. The technical scope of control is related to the technical degree of complementarity between the systems elements. In the Western European electricity system, this would be the technical boundaries of the ENTSO network across all 24 interconnected national systems.[14] The institutional scope of control is typically defined by the national or international (regional) boundaries.

Finger et al. (2005) relate the degree of coherence between institutions and technology to the above-mentioned coordination mechanisms. Coherence refers to a situation in which the essential functions are accommodated by similar coordination mechanisms with a comparable scope of control. Obviously in the case of incoherence there are differences between the technical and institutional coordination mechanism (i.e. centralized, decentralized or peer-to-peer) or the technical and institutional scope of control. In that case Finger et al. (2005) expect repercussions with respect to the technical system performance. Infrastructure performance, or system performance, reflects client desires or expectations with respect to the economic performance (e.g. efficiency), public services (e.g. universal service obligations), and technical performance (e.g. reliability and security of supply). As mentioned above, coherence theory only deals with the technical systems performance. Incoherence is expected to be negatively related to the technical system performance. If, for instance, the above-mentioned technical scope of control (UCTE area) is different from the institutional scope of control (national boundaries), inferior system performance can occur as a consequence of insufficient coordination between the different national systems. An example can be found in the sudden and unexpected international electricity currents over the Dutch network as a result of German windmill capacity. These electricity currents use the Dutch transport capacity and may jeopardize the national system. In this case it acts as an integrated technical system, while the institutional system is delineated by the national boundaries. We will further discuss this issue in Chapter 7.

We argue that the coherence might become incoherent according to two possible routes: (1) a change of the institutions of the system (arrow 1), (2) a change of the technology of the system (arrow 2).[15] From this perspective – and other co-evolutionary perspectives (e.g. Perez, 2002, Tunzelmann, 2003) – it is implicit that change is as follows. First there is a situation of alignment (i.e. equilibrium) which is followed by a discontinuity. This on its turn is followed by a shift towards aligment and a new equilibrium. This process is depicted in Figure 12. The incoherence results in a unsatisfactory functioning of the system, i.e. a certain performance (Finger and Künneke, 2007) that does not match with the desired performance in terms of economic performance, guarantee of public values and technical system integrity.[16] We argue that this unsatisfactory functioning of the system (or performance gap) results in a need to adapt the system – either by institutional change or by modernization of the technical system – in order to attain the desired performance. In this research we are particularly interested in the relation of alignment and misalignment and the technical system adaptation which we call modernization.

An important point is that coherence does not have to be the system's objective. Although we qualify the adequate safeguarding of the critical functions as coherent, we do not approach this issue normatively. One could also imagine that we should strive for less coherence in order to trigger innovative activity.

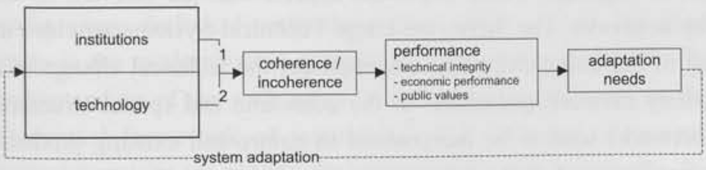

Figure 12 Sequence of coherence and system adaptation
Source: Partly adapted from Finger et al. (2005)

It should also be noted that there is a trade-off between the different categories of performance. Even if technological performance deteriorates as a consequence of incoherence, economic performance might be superior or public services might be unchanged. For example, a lack of investments in the network might increase the economic performance, but will have a negative effect on the technical performance of the system. Hence there is no unidirectional relation between incoherence and all categories of infrastructure performance. Coherence theory has not yet addressed these possible trade-offs and has merely focused on the technical performance of the system. The definition of different performance indicators and the level to which they should be attained is based on the desires and expectations of its users. For instance, system reliability can be operationalized as the inverse of the number of interruptions or the number of minutes of interruptions. However, what we regard as good or bad performance depends at large on societal expectations and desires.

In conclusion, we argue that the coherence approach seems a promising approach for assessing specific aspects of the interrelation between institutions and technology in electricity systems with a focus on the essential functions that need to be safeguarded to guarantee a good performance of the system. Modernization might be related to aspects of coherence or incoherence and hence provide new insights into the process of technological and institutional change of electricity systems. With regard to the limitations of the approach we note that existing coherence literature uses a static comparative approach, while a more dynamic approach should be incorporated in our research to allow for understanding the dynamics and a better understanding of the variables involved in the process with regard to modernization and coherence. Furthermore, although coherence theory makes a distinction in economic performance, technical performance and public values (e.g. Finger et al., 2005), existing coherence literature has primarily focused on the technical performance of the system and existing theory on coherence misses a framework for assessing the trade offs between economic performance, technical performance and public values. These trade-offs are important in the modernization of electricity networks. We will elaborate on solutions for these drawbacks in more detail in the next section.

2.4.5 Framework 1 for empirical research

The theories addressed above highlight some important aspects that are relevant to the modernization of electricity networks. The theory on Large Technical Systems provides us with a good understanding of the complexity that encompasses the technical change of a large system as the electricity network embedded in the economic and spatial structure. Innovation in electricity networks tend to be incremental in nature and existing products and technologies undergo processes of slight, continuous improvement rather than radical change. Furthermore, technical alignment is involved in embedding new technologies in the existing technical structure. This theory is clearly linked to transition theory that provides us with the concepts with which to describe the long term change of infrastructure systems. The conceptual levels of transition theory are applied to processes that have a clear systemic character, e.g. the socio-technical regime. However, in our research we aim to make an explicit distinction between the institutional part and the technical part of the socio-technical system. This distinction is necessary for both of the proposed analytical perspectives with regard to modernization. The co-evolution theory is the overall view with which we cover the perspective on the alignment of institutions and technology. Coherence theory provides us with a set of critical technical functions – capacity management, interoperability and interconnectivity – that have to be aligned with the institutions in order to attain and maintain a desired performance of the electricity system. We make a further distinction of the institutions in order to specify the drivers in the modernization process by applying the layered approach of Figure 10. These layers allow us to structure the many institutions that we will encounter in our empirical research and it enables us to determine a possible logic between the institutional layers (addressed in section 2.3.2). In this analytical perspective of alignment we omit the actors and games level of analysis as we analyze modernization at a higher level of abstraction.[17] The question that we pose makes the levels of informal institutional environment, formal institutional environment and the institutional arrangements the relevant and important layers for this part of the research. By applying the conceptual framework as described above, and given that each of this critical technical functions – capacity management, interconnectivity and interoperability – might be supported by institutions at a certain institutional layer, we are able to relate the critical technical functions to the different institutional layers.

This brings us to the framework with which to describe and analyze our empirical findings. First we describe modernization from a socio-technical perspective and focus on the general features and developments with a focus on the technology and institutions in modernization. We refer to this as the socio-technical context of the specific variables or relationships that we aim to analyse. The socio-technical context allows us to pinpoint when and how technical functions become critical and to identify the institutions at certain institutional layer that were important in the modernization. This, furthermore, enables us to identify the dynamics of the important variables in modernization that would not have been revealed by a static comparative coherence approach. The socio-technical context allows us also to incorporate the trade offs of the different performance elements: economic performance, technical performance and public values. We focus on the actual decisions made in the modernization process based on these trade-offs. This will allow for a better understanding of the wide array of drivers in modernization. Subsequently, we apply the conceptual framework of institutional and technical alignment to analyze how certain critical functions are coped with institutionally and technically. By structuring the empirical process in this way we are able to identify the drivers in modernization from the perspective of the alignment between the institutions and the technology.

Figure 13 presents the framework for empirical research. Although we focus on the network part of the electricity system we also take part of the generation and consumption into account where relevant for explaining the relation between alignment and modernization of the network. First is a socio-technical context that surrounds the modernization. The link between the institutions and the technology (arrows 1 and 2) results in either an aligned or misaligned system. As emphasized in section 1.4 we focus on the alignment between technology and institutions. However, we also consider the socio-technical system perspective in which technologies in a large technical system have to be aligned. Any misalignment in the technical domain may cause friction and can induce mnodernization as well. For example, as addressed in section 2.4.4 the generation, transport and consumption function should be technically aligned. That is to say that its installed capacities should be of the same order of magnitude to make the system work properly. This capacity management can be framed in the coherence perspective (section 2.4.4) of long term capacity management. It can also be framed in the previously addressed socio-technical/LTS perspective (section 2.1 and 2.4.1) as a technical alignment of the system. Misalignment leads to a performance of the system below the aspired level. This underperformance is supposedly an impulse for adaptation of the system. The system can be adapted technically, i.e. by modernization (arrow 3), which results in a modernized technical system (4). It can also be done through institutional change, i.e. changing the institutions in place (arrow 5).

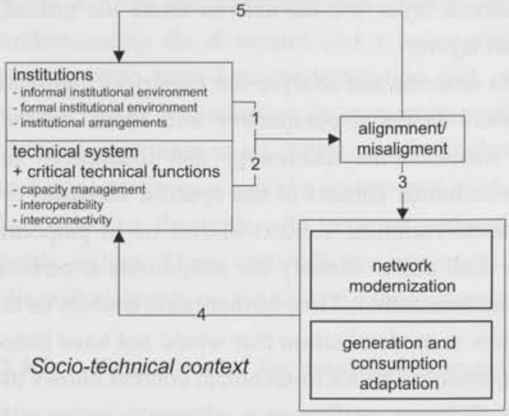

Figure 13 Conceptual framework of the alignment perspective

The concepts of institutions, technology, critical technical functions, alignment and modernization are to be explained within the model, i.e. these variables are considered as being endogenous.[18] For example, the modernization is explained by the misalignment which on its turn is explained by the critical functions, which is explained by other relevant concepts. A further discussion on the methodology with which to approach the empirics, how we deal with the endogenous and exogenous variables and the operationalisation of the important concepts of this research is discussed in Chapter 3. This chapter, furthermore, makes the concepts as presented in this chapter more operational.

2.5 Innovation system perspective

In the following section we discuss some key concepts of technical change and we elaborate on theories relevant to technical change from the analytical perspective of innovation systems.

2.5.1 Key concepts of technical change

Schumpeter (1934) classified technical change, or innovation, into a number of types of which two have received most attention in economics (Fagerberg, 2005): (1) the introduction of a new product and (2) the introduction of a new method of production.[19] Processes of technical change can, subsequently, be divided into the sub processes in the innovation process such as technology creation (invention) and technology adoption (Knight, 1967; Dewar and Dutton, 1986b; Ghoshal and Bartlett, 1988; Voss, 1988). Innovation is thus conceived as a process of multiple phases instead of an event occurring at a single point of time. That is in line with Pierce and Delbecq (1977: 28) according to whom it 'seems useful and consistent to follow the tradition of Thompson (1965) and define innovation as the generation, acceptance and implementation of new processes, products, or services for the first time within an organization setting.' Evolutionary economists refer to the phases in the process of technical change as *variation* and *selection,*[20] Variation of technology exists because of deliberate or unintended innovation. The variety of (deliberate) innovation is not completely arbitrary but is in a certain way pre-determined, or bound by the *technological paradigm*, 'a model or pattern of solution of selected technological problems based on selected principles derived from natural sciences and on selected material technologies' (Dosi, 1982: 152). Dosi introduced this term to describe the framework in which technical change takes place. The direction of technical change follows a certain *technological trajectory* or, 'a cluster of possible technological directions whose outer boundaries are defined by the nature of the paradigm itself' (p.154). Evolutionary economists have traditionally distinguished between radical and incremental innovations based on the technological trajectory. Incremental innovation is a more evolutionary pathway and a step forward along a technology trajectory (Dosi, 1982), with a high chance of success and low uncertainty about outcomes. Most innovations are of this incremental type (Rosenberg, 1982; Nooteboom, 2000a). Radical innovation, on the other hand, involves larger steps in the advancement of a technology or process. Radical innovations represent an entirely new class of products or technological devices based on a novel set of engineering and scientific principles. Saviotti's (1996: 65) criterion is in line with this defining radical as an 'innovation which leads to a new internal [physical] structure' or that has a new working principle. Incremental innovation is 'an innovation which improves services without any qualitative change in internal or technical characteristics.' Despite these definitions, in practice the distinctions sometimes prove hard to make. Dewar and Dutton (1986a: 1423) note that 'the distinction between radical and incremental innovations is easier to intuit than to define or measure', as people may differ in their judgment of incremental and radical towards innovation based on their frame of reference as these distinctions rely on perceptions of new knowledge embodied in the innovation. We also emphasize that the categories of radical and incremental are not intended as exclusive categories but as two ends of a continuum, with slightly incremental at one end and highly radical at the other end (Orlikowski, 1991; Dess and Taylor, 2004). This complies with our understanding of modernization and the sliding slope of conventional modernization (i.e. slightly incremental change) and innovative modernization (i.e. more radical change) (also addressed in section 1.3).

Another distinction prominent in innovation theory are the forces that drive the process: on the demand side the process can be 'pulled', on the supply side the process can be 'pushed', but mostly it is a combination of both forces operating and interacting at each stage of the innovation process revealing a characteristically iterative process (Mowery and Rosenberg, 1979; Barras, 1986; King et al., 1994; Swann, 1994). With regard to the electricity sector we consider an incoherent system with its underperformance as a pull for modernization. The equipment suppliers in the electricity sector might have a large role in the push of a certain technology, while the network companies might have a large role in the pull of a certain technology. Both these actor groups are considered as important in the innovation system of the electricity sector.

Another key concept in evolution is *path dependence* meaning that the decisions that people make today are strongly constrained by the past and the decisions taken today will strongly influence the room to manoeuvre in the future. The linkages of the past to the present and the future are captured by the concept of *path dependence*. In the words of David (1985: 332): "A path-dependent sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happen-stance dominated by chance elements rather than systematic forces". This implies that the flexibility to adapt the electricity system is rather low and changes take place at a slow pace. Whereas network elements may last 40-70 years, the network structure of the electricity system may last much longer.

2.5.2 Innovation in network organizations and innovation systems

Specific aspects in the institutional setting of network industries suggest specific behaviour towards innovation of its relevant actors. Most network industries, such as the electricity industry, were in recent history vertically integrated and not acting under competitive market conditions. For the electricity industry this had at least two important reasons. First, the electricity system used to have strong economies of scale characteristics (as addressed in section 1.2). From the 1930s until the 1980s there was a constant drive to build plants with higher capacities in order to reduce the cost per installed MW (Hunt and Shuttleworth, 1996). This economy of scale was accompanied by increasing initial investments which reduced the number of market actors. These economies of scale characteristics caused the networks to be characterized as so-called 'natural monopolies' (Künneke, 1999) of which many used to be state monopolies in Europe. Williamson (1965: 68) states that '[a]lthough an a priori case can be made for the proposition that a monopolistic market structure enhances both the rewards and pressures for the largest firms to innovate, a case can also be made for the opposite.' In other words, the relationship between monopoly and innovation remains ambiguous. Furthermore, energy companies had a large responsibility to fulfil certain public values such as reliability, affordability and security with their services (e.g. WRR, 2000; Bijkerk et al., 2003). This could also have an impact on innovative activity.

Currently, the network parts of these former natural monopolies operate in a regulated environment, while the production and trade of electricity are liberalized. These regulatory aspects of the electricity industry determine the behaviour of its actors toward innovation. As Winston (1998: 91) puts it,

> neoclassical economics predicts that [..] any profit maximising firm should always wish to minimize its costs, regardless of how much competition it faces. But a regulated firm is in a different situation. Although regulated firms can choose their technologies and operating practices, these choices are made subject to the state's control over prices, entry, and exit and without the challenges posed by unrestricted competition, hence managers and employees face a rather different set of incentives in searching for greater efficiency.

The relation between the institutions and the innovative performance is extensively investigated in the so-called National Innovation System literature (Freeman, 1987; Lundvall, 1992; Nelson and Rosenberg, 1993). In such an innovation system, the "institutional selection environment functions as a set of 'signposts in innovative behaviour, 'selecting' […] the type and direction of innovative paths in society." (Steen, 1999: 93). Innovation system literature considers the institutions of an economic system as the constraints and incentives impacting on innovation. A consensus is absent on the exact definition of a system of innovation or innovation system, but a common definition is given by Metcalfe (1985: 212), who describes an innovation system as

> that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies

We structure the institutions that coordinate transactions in the innovation system according the layers of Figure 10. It is demonstrated that these layers can provide a logic that is characterized at system level as the 'Anglo-Saxon model, Continental European and Asian model. Nooteboom (2000b) demonstrates how institutions coordinate inter-organizational relations by enabling and constraining forms of coordination. He shows how this impacts the innovative performance in a cross country comparison of the US and Germany and how these different innovation systems result in different types of innovation, i.e. radical or incremental innovation. Whereas the US is more flexible, market oriented with multiple short term formal relations, Germany is more oriented towards stable long term networks between organizations. The performance outcome is that the production costs in the US are relatively low and the transaction costs high, while in Germany it is the opposite, i.e. the production costs are higher and the transaction costs are lower. With regard to the innovation performance it was found that in the US radical innovation is more prominent while incremental innovation is more prominent in Germany (Nooteboom, 2000b). Such analysis of the relationship between the institutions and the type of innovation can also be performed at regional level, referred to as the regional system of innovation (Braczyk et al.,

1998) and sectoral level, referred to as the sectoral systems of innovation (e.g. Malerba, 2004).

Although this approach considers technical change and innovation processes to be a result of a set of interacting institutions, the innovation system literature is often of a comparative static nature. However, as presented in the framework in Figure 14 the relationships between the institutions in the different layers can also be analyzed in a dynamic way. In other words, instead of assessing the status quo we can assess the (longitudinal) developments within the innovation system. This enables us to better disentangle the variety of institutional drivers that play a role in the modernization process of electricity networks.

Next to the institutions affecting the actor from outside, we also addressed the institutions within the actor (see section 2.3). In other words, we open the black box of the actor and further explore which attributes within the actor determine innovative activity. Next to the institutional incentives at firm level, also the firm level technological capabilities – the skill set of a firm – play an important role (see e.g. Lall, 1987; Katz, 1987). The importance is reflected by the OECD that explains long-term differences in the performance of advanced industrial economies as follows:

> Over the longer term, economic growth arises from the interplay of incentives and capabilities. The capabilities define the best that can be achieved; while the incentives guide the use of the capabilities and, indeed stimulate their expansion, renewal or disappearance. In the advanced economies, the capabilities refer primarily to the supplies of human capital, of savings and of the existing capital stock, as well as to the technical and organizational skills required for their use; the incentives originate largely in product markets and are then more or less reflected in markets for factor supplies thereby determining the efficiency with which capabilities are used. Both incentives and capabilities operate within an institutional framework: institutions set rules of the game, as well as directly intervening in the play; they act to alter capabilities and change incentives; and they can modify behaviour by changing attitudes and expectations. (OECD, 1987: 18).

These capabilities are often divided in several categories based on their functionality (e.g. Dahlman et al., 1987). Another way of categorizing these is according to the innovativeness of those activities (Lall, 1992) for which two categories are distinguished. First are the routine capabilities, which can be described as the skills and knowledge to handle a certain technology. This category relates to the routines as described by Nelson and Winter, as being 'regular and predictable behavioural patterns' or alternatively 'repetitive patterns of activity in an entire organisation' (Nelson and Winter, 1982: 97). The second category is the innovation technological capability, which can be described as the skill to change a certain technology (Bell, 1999).

2.5.3 Framework 2 for empirical research

The theories as discussed above highlight a number of important concepts relevant to our framework for empirical research with regard to the innovation perspective. The focus of our perspective is on innovations in products for the electricity network rather than on the processes to make these products. The products are the elements that are implemented in the existing system as a way to modernize the electricity system. We learned from theories above (section 2.1) that the current electricity network is socio-economically and technically embedded. In other words, the existing electricity system is an important determinant in the possibilities for future innovative pathways, i.e. the system's development is path dependent.

An important aspect is the (institutional) incentives for the main actors in this innovation process. In general, we have learned above that the electricity sector has specific network-related characteristics, and hence, different drivers impacting on innovation are expected compared to industries that are not related to networks. We do not rely on innovation variables from literature in our empirical framework; because of the specificities of the electricity sector and the lack of knowledge on these variables we take a more explorative approach in determining the variables affecting innovation. A major focus of our conceptual framework is the role of the innovation system. In this perspective we consider the institutions as guiding principles for the innovation of the network operator and the technology supplier. As in the previous analytical perspective we conceptually divide the institutions into layers according to Figure 10. We consider the informal institutional environment, the formal institutional environment, the institutional arrangements and the actors and games as important determinants for modernization (see Figure 14). Next to the institutions within the actors we pay attention to the innovation capabilities of the actor. In this perspective we take the institutional variables as exogenous.[21] These institutional variables explain the innovation part of modernization. This latter variable is thus the endogenous variable. This is further discussed in Chapter 8. Similar to perspective 1, the institutional layers allow us to find a certain institutional logic, the case in which the layers are complementary in the whole institutional system (see section 2.3.2).

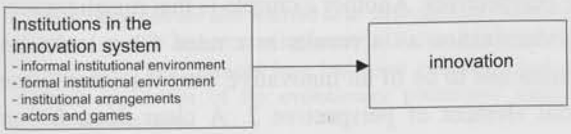

Figure 14 Conceptual framework of the innovation system perspective

2.6 Summary and conclusion

This theoretical exploration provided us with a number of useful concepts with which to refine the conceptual framework for both analytical perspectives (1) the alignment perspective and (2) the innovation system perspective. The conceptual framework of perspective 1 allows us to identify the variables in the modernization process with regard to the alignment between institutions and technology and between technology and technology. The conceptual framework also enables us to pinpoint important institutions at different analytical levels and it enables us to assess whether the technical system with a set of critical functions is safeguarded, which subsequently has its impact on the alignment of the system. Any misalignment may lead to a certain underperformance which supposedly drives institutional change or modernization. The conceptual framework of perspective 2 allows us to identify the drivers in the modernization process from the perspective of innovation systems. It enables us to pinpoint institutional drivers and barriers to innovation activities that are important for the relevant actors. It also enables us to assess at which institutional layer the variables are more prone to stimulate and hamper innovation. Both perspectives allow us to determine a certain institutional logic of the system (sections 2.4.5 and 2.5.3).

We do not consider any of both theories in the two perspectives as more adequate than the other as in theoretical monism. Theoretical monism considers the existence of different theories addressing the same set of phenomena as a temporary state that has to be overcome eventually with the 'survival' of one of the theories. We rather consider the perspectives to focus on different parts of the issues or phenomena in the study and argue that these perspectives are complementary. This is referred to as theoretical pluralism (Groenewegen and Vromen, 1996). Theoretical pluralism considers that no single theory is able to fully explain some set of phenomena on its own. In conjunction the two perspectives yield more insight in the modernization phenomena than any single perspective would. The complementarity in our perspectives can be illustrated by the following. The innovation system, which is part of perspective 2, can drive a certain innovation, for example AC technology. This innovation has an impact on the technical system and the critical functions, concepts from perspective 1. In this example, the introduction of AC technology is accompanied by the capacity management function of load balancing in order to avoid any misalignment in the system. This is an example of a driver in the innovation system of perspective 2 that implicates the essential elements in the framework of perspective 1 as an example of complementarity of the two perspectives. Another example is that misalignment in perspective 1 can be a driver to modernization as it results in a need for a technical solution. In cases where this modernization has to be of an innovative kind it relates to the innovation system which is an essential element of perspective 2. A clear need for an innovation can be a driver for the innovation system to deliver the appropriate new technology. This is yet another example of how the two perspectives can address different parts of the modernization phenomena. In sum, the two analytical perspectives emphasize different parts of the modernization process and result in the identification of different drivers in this modernization process.

Notes on Chapter 2

[1] Note that Weijnen and Bouwmans (2006) also consider a level of service provision to the end user. We consider this category as a result of modernization processes at the level of physical facilities and management and control.

[2] Some scholars also include the public values in the performance of the system as we discuss in 2.4.4.

[3] 'Investment in quality has received little attention in theory and policy thus far. An explanation could be that quality has many dimensions and is difficult to measure and to value.' (von Hirschhausen et al., 2004: 208)

[4] Adequacy is a measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account planned and unplanned outages of system components. Security is a measure of power system ability to withstand sudden disturbances such as electric short circuits or unanticipated losses of system components or load conditions together with operating constraints. Another aspect of security is system integrity, which is the ability to maintain interconnected operations. (CIGRE, 1992).

[5] One could theoretically also consider neutral effect of certain technologies.

[6] However, Kirschen and Strbac (2004) argue that a mere expansion of the transmission lines does not necessarily improve the security of the system, because the additional capacity that it provides is used to increase the power transfer between the two areas rather than to increase security' (p. 34).

[7] For an extensive overview of the literature on institutional economics we refer to Rutherford (1994), Bush and Tool (2003) and for overviews of the new institutional economics to Eggertsson (1990), Furubotn and Richter (1998) and Menard and Shirley (2005).

[8] A smart grid can be described as a grid delivering electricity from suppliers to consumers using two-way digital technology to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency

[9] There is, however, a discrepancy of the use of the concept of institutions and the incorporation of the informal institutions, such as culture and norms. In this research we view the concepts of institutions as discussed in 2.3.

[10] Reactive power refers to the phenomenon where the voltage and and the current are out of phase. The current associated with reactive power does not provide net tranfer of energy to the load, but has to be taken into account when sizing the capacity for the conductors, transformers and generators of the system.

[11] In this publication the system management concept is related to the technical scope of the network, instead of distinguished as a separate critical technical function.

[12] Reserve capacity is a function of installed capacity and demand.

[13] Source: www.tennet.org/transport_en_systeemdiensten/procedures_regelgeving/codes/netcode.aspx

[14] Source: www.entsoe.eu/association/history/ucte/

[15] or a change of both the technology and institutions of the system.

[16] However, any unsatisfactory functioning of the system (or performance gap) is not necessarily a coherence issue. Incidents that cause blackouts in the electricity system are not conceptualized as coherence issues in our framework. A performance gap is thus merely an indication for an incoherent system.

[17] In the innovation system perspective we incorporate this level in the model.

[18] Endogenous variables are explained within the model, whereas exogenous variables are not explained within the model. These exogenous variables are the explanatory variables that are given and constant.

[19] These categories are also referred to as innovation of product technology and production technology (Smookler, 1966), and product and process innovations (Nelson and Rosenberg, 1993).

[20] These terms are borrowed from biological evolution theory (Metcalfe, 1989). See e.g. Basalla (2005) for an empirical application of the evolutionary perspective using novelty, diversity and selection as the main explanatory concepts.

[21] However, where appropriate we want to shed light on the emergence of certain institutions within the innovation system and hence explain the origins of these institutions, therewith making the institutional variable endogenous.

Part 2 Alignment perspective

3 Methodology

In this chapter we address the perspective of the alignment of technology and institutions referred to in short as the alignment perspective. We discuss the research approach with which to explore the relationships between modernization and the alignment. Subsequently, we discuss the way the data are collected and how the relationships are analyzed. We, furthermore, explain how the history of electricity systems from the first power system to the present is divided into four distinctive periods based on important modernization processes. We conclude this chapter with a description of the structure of the chapters 4–7 in which we address the four important periods of modernization.

3.1 Research question

We are interested in the variables in the modernization of electricity networks in the Netherlands from an alignment perspective. The main research question with regard to the alignment perspective is the following:

What are important variables in the modernization of electricity networks in the Netherlands from the alignment perspective?

The research subject at hand is until now unexplored in co evolution literature. In order to build theory on this subject our research is of an explorative nature. This implies that we will not test hypothesis that can be derived from already well established theories, but that we aim to contribute to the generation of hypotheses by identifying important variables and relationships in modernization.[1] These are not hypotheses in the strict logical deductive sense, but rather patterns of models (see also section 1.5). By disentangling the modernization of electricity systems, we identify, for example, certain critical functions, like capacity management, interoperability and interconnectivity (section 2.4.4), which together with the institutions result in either an aligned or misaligned system. This supposedly has a feedback on the institutions or on the technical system. That is to say that misalignment of the institutions and the critical technical functions of the system, might act as an explanatory variable that drives modernization of the system. This leads us to the sub question: can misalignment act as a variable impacting on modernization? Also the opposite might hold, i.e. misalignment might be needed to trigger modernization. This leads us to the following sub question: can alignment act as a variable impacting on modernization? Another possibility is that the misalignment leads to institutional change. This is depicted in the left hand side of Figure 15. On the other hand, we might expect that modernization makes certain functions critical which therewith causes misalignment. Additionally, it can be argued that an institutional change might cause misalignment by changing the existing institutions that supported the critical functions. This is depicted in the right hand side of Figure 15. Thus, our next sub question involves the relationship between technical modernization and alignment: can modernization act as a variable with an impact on alignment, or misalignment? Next to determining the interrelations of the variables in the modernization of electricity networks we aim to determine the circumstances under which these relationships occur.

Furthermore, next to the alignment between institutions and technology we aim to assess the alignment of different technologies in the electricity network, which we referred to as technical alignment (see section 2.4.1). This can be graphically presented by substituting the institutions and institutional change in Figure 15 with technology and technological change respectively.

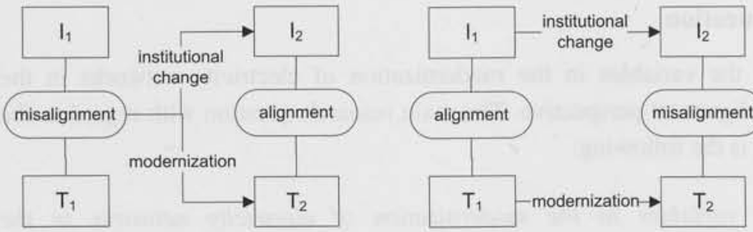

Figure 15 Conceptual model of modernization and alignment
I: institutions; T: technical system with critical functions

We also aim to identify other relationships – beside the relation between the concepts of alignment and modernization – specifically with regard to alignment and institutional change. This leads us to the sub question: what patterns of institutional variables can be identified with regard to the link between modernization and alignment?

In order to obtain a dynamic perspective of the relationships between modernization and alignment we choose an historical analysis of the Dutch electricity sector. There is a number of historical analyses of the power systems (e.g. Hughes, 1983; Hesselmans, 1995; Patterson, 2004; Verbong and Geels, 2007; Verbong and Vleuten, 2004; Zantinge, 2004). Our approach differs from the other existing historical analyses in being an interpretation of history from the perspective of modernization and the alignment of institutions and technology. We divide the time between the start of the first power system and the present power system accordingly in a number of periods, based on important modernizations. This will be further discussed in section 3.4.

In sum, the following sub questions are posed:

- Can misalignment act as a variable impacting on modernization?
- Can alignment act as a variable impacting on modernization?
- Can modernization act as a variable with an impact on alignment, or misalignment?
- What regularities can be identified with regard to the link between modernization and alignment?

Again we emphasize that next to determining the impact of the variables on each other in the modernization of electricity networks we aim to determine the circumstances under which the relationships of these variables occur.

3.2 Research approach

We initially consider the concepts of institutions, critical functions, alignment, modernization and the technical system with its critical functions as endogenous variables. In other words, every variable can be explained within the model by the other variables. However, in order to analyze history and certain steps in history we will use the method of isolation. This is explained in the following.

> *Material isolation* occurs when a system is experimentally isolated from the causal influence of other systems, or when such an actual isolation occurs spontaneously, without artificial intervention. In a *theoretical isolation*, a limited set of items is assumed to be isolated from the involvement or influence of the rest of the world, in analogy to experimental isolation. (Mäki, 2004: 321).

Given 'the inherently poor experimental quality of social phenomena' (Wilber and Harrison, 1978: 67) we use theoretical isolation, focusing on a limited set of items and analyzing relationships that are involved in the modernization process from a alignment perspective. The isolations analytically highlight parts of the world into two sets of items, the explaining items, also referred to as the explanantia, or exogenous variables, and the set of explained items, also referred to as the explananda or endogenous variables (Mäki, 2004). What we consider exogenous and endogenous depends on the phenomena addressed in the sub question and on the state of a variable. We may analytically exogenise variables to isolate the issue from the context. Additionally, in case that a variable is static during the period under analysis, we may consider this as an exogenous variable. This method of isolation allows us to identify different relationships of the above-mentioned variables. For example, in one illustration institutions can be taken as exogenous in assessing the alignment. In a next illustration we can take the alignment as exogenous and observe the result from that, such as institutional change and technical change, as endogenous. In yet another instance we might consider modernization as given and assess the influence of modernization on the technical system and its critical functions.

Moreover, as we consider the electricity system as the whole chain from generation to load, we sometimes will describe technical adaptations outside the electricity network but within the whole electricity system. For example, the capacity management clearly has the component of the generation and the consumption under its technical scope. Changes in these parts of the system could be qualified as a modernization of the electricity system instead of modernization on the electricity network. So what is exogenous for the electricity network can be endogenous for the electricity system.
We structure institutions along the institutional levels in Figure 10 to determine a possible logic (see section 2.3.2).

3.3 Data collection and analysis of the empirics

We started the data collection with desk research as one of our methods and used additional interviews as the other method. Using two different methods is a technique in qualitative research to increase the credibility and validity of the results. The desk research provided us with an assessment of the key concepts as input for the analysis of the relationship between modernization and alignment. The sources we used are historical studies on specific electricity companies and historical literature on the development of the electricity sector. We selected literature on the development of electricity networks in the Netherlands from the start of the electricity systems around 1880 until the present. For example, Hesselmans (1993), who provides us with a detailed history of the development of the electricity sector of the Netherlands. Buiter (1994) addresses the history of the electricity cables in the Netherlands, while Vlijm (2002) provides us with a history of the energy company of the province of Gelderland and addressing the link between the government and the electricity sector. Next, literature was studied from the specific perspective on alignment and modernization. We, furthermore, analyzed the identified relations between technology, modernization, institutions, institutional change and critical technical functions. We did not expect to find historical studies that are framed in our conceptual framework as studies on alignment are still rather limited. This implies that we needed to actively search for relevant connections to our conceptual framework. A number of initial interviews with key experts from the electricity experts were conducted to validate the findings of the desk research and to enrich the data with current alignment issues. Questions in these interviews related to current and past issues and trends with regard to electricity networks (see Appendix B).

3.4 Determination of periods in electricity development

We divided the time from the first power system until the present in four periods based on large modernization processes. So our starting point is technological change. We note that the transition from one period to another is not always abrupt. These periods are not bordered by strict chronological boundaries but serve as a way to show distinct features with regard to modernization (Table 1).

The first period is characterized as a period of a shift from DC to AC technology, which started around 1880 and ends somewhere in the 1910s.[2] This AC technology opened the way for expansion of the electricity systems. Electricity production in this period is characterized as dispersed and decentral (Buiter, 1994). The shift to AC was accompanied by a lot of experimentation and can therewith also be described as a period of pioneering (Heuvel, 2002; Verbong and Vleuten, 2004; Boersma, 2006).

The second period is the period of electrification of the Netherlands (Heuvel, 2002), i.e. the establishment of electricity generators and the large scale connection to the consumers.[3] This period starts around 1912 in which year the provincial concession regulation came about. This was an impulse for provincial companies to establish energy companies, which were used to electrify the Netherlands. Around 1930 the electrification was well on its way and in 1939 it was almost 100% (Hesselmans et al., 2000b). This marks the end of the electrification period.

The third period starts in the 1940s and is characterized as a period of reinforcements and interconnections of the electricity network. The subsequent decennia are characterized in modernization terms as a period of scale increase and expansion of the electricity system as a result of the strong demand growth (Verbong and Vleuten, 2004). This period ends with the first energy crisis in 1973, which resulted in a major drop in the demand growth of the 1950s and 1960s (Heuvel, 2002) with implications for the previous scale increase and expansion of the network.

The fourth period starts after the oil crisis of 1973. This period can be technically characterized as shifting from a centralized generation system to a hybrid system of centralized generation combined with distributed generation (Verbong and Vleuten, 2004). Institutionally this period was characterized as a period of liberalization and privatization (Heuvel, 2002; Verbong and Vleuten, 2004).

Table 1 Periods in the development of the Dutch electricity system

Characterization	Period
Shift to alternating current	1880s-1910s
Electrification	1910s-1930s
Reinforcement and interconnections	1940s-1970s
Shift to a hybrid system	1970s-present

3.5 Structure per chapter on each period

We discuss each period of modernization in a separate chapter. First, we address the socio-technical context of the modernization. We address the status of the technical system and dynamics relevant to the system. We first focus on the technical aspects after which we focus on the institutional aspects of the electricity system within the socio-technical context. In the next section we combine the technological and institutional view. We analyze why certain technical functions became critical and how this criticality was coped with institutionally or technically. The institutions in this section are specifically related to the critical functions. Finally, we list the identified relationships between modernization and alignment. We conclude each chapter with a discussion on the identified relationships.

Notes on Chapter 3

[1] A hypothesis is a proposition that is not (yet) proven. It is a starting point of a theory, explanation or derivation and consists of a suggested explanation for an observable phenomenon.

[2] See also McNichol (2006).

[3] Until 1912 the institutional responsibility of the electricity supply was at municipal level (Hesselmans et al., 2000b)

4 Shift to alternating current

We start this chapter with an elaboration of the specific socio-technical context of this period of shifting from DC to AC technology, covering the 1880s-1910s with a focus on technology and institutions in this period. We address the balancing of the electricity system as a result of AC and the expansion of the network that was enabled by the shift to a system with alternating current. Furthermore, we list the identified relationships between the shift to alternating current and alignment of institutions and technology.

4.1 Socio-technical context

In this section we elaborate on the socio-technical context of the shift to AC technology as an important modernization of the electricity network. We first highlight some important issues with a focus on the technology and technological trends. After that we highlight some important institutional issues structured along the institutional layers of informal institutions, formal institutions and institutional arrangements.

4.1.1 Technology

The first electricity systems in the Netherlands were installed in the 1880s serving customers in its close proximity. Light in the form of the bulb lamp was the prime application of electricity in the 1880s (Overbeeke, 2001). The factories and work shops in large cities were the important first users of electricity. Many of these companies owned a steam or gas engine to generate electricity (Noort, 1993b). Local companies provided local electricity services through a DC network. The area of supply was limited as DC technology lost substantial power in the transportation of the electrical energy.

It was a pioneering period and especially the west of the Netherlands was a large experimentation laboratory for initiatives with regard to electricity supply (Buiter, 1994). The invention of the rechargeable battery was followed by continuous improvements. These batteries could be used for DC networks. Another technology was the dynamos which gave way to affordable constant alternating current (AC) electricity supply centrally generated. The dynamos constructed in 1880 were able to generate some tens of kWs (Hesselmans, 1993). Furthermore, the development of the transformer as, as presented in Paris in 1889, made transport of electrical energy along longer lines economically feasible with AC. With AC technology larger areas could be served with much lower energy losses.[1] Three forms of electrical lighting emerged from these initiatives: (1) separate installations (mostly in shops, hotels, workshops and residences), (2) block stations: adjacent buildings that were supplied from one generator or dynamo and (3) central stations which supplied up to a few streets. Separate installations were the most common form.

From the coherence perspective (section 2.4.4) we note that shift from DC to AC resulted in a new critical function: load balancing (Pepermans et al., 2005), which we also refer to as short term capacity management. This critical function will be further discussed in section 4.2.1. In 1891 most central stations were still DC stations (Noort, 1993b) with a limited reach of a few hundred meters (Buiter, 1994). Around 1900 the variety increased although most plants remained to work with DC technology. After 1904 AC technology was chosen as the most appropriate technology for the majority of the electricity companies of significant size (Hesselmans and Verbong, 2000).

At the end of the nineteenth century electricity became important for more that just lighting with the increasing use of electro engines in industry and electrical trams. This resulted in a large increase in the number of central stations. Furthermore, in the period 1900-1910 the Netherlands were provided with a tight network of tram lines (Buiter, 1994). In all big and many small cities central electricity plants were erected in order to supply extended areas (Verbong, 2000). In 1906 the Hague had the first municipal electricity company (Noort, 1993a). In general, small private companies started to be replaced by larger municipal companies as the little private electricity systems could not fully compete with the central stations of municipalities (Noort, 1993a) which supplied at a larger scale and could, due to economies of scale, operate at lower costs per kWh produced. In the Netherlands the idea for district service, i.e. servicing larger areas, came up in 1905, foremost as a result of initiatives from the private sector. For example, the company Twentsch Centraal developed plans to sell electrical energy to 100 municipalities in the provinces of Overijssel, Gelderland and the south of Drenthe (Boersma, 2006).

4.1.2 Institutions

With regard to the public norms and values related to electricity we found that until 1890 electrical light was considered as a luxurious good. It would take until 1913 with the introduction of the Philips' half Watt light bulbs before electrical lighting was considered an ordinary product for daily life by the general public (Hesselmans and Verbong, 2000). As it was not yet considered as a universal service and the general public was not very dependent on it. Electricity, however, had in crucial ways to compete with the existing gas system. This means that reliability and affordability of the electricity were at this time already issues that played a role in the choice of the electricity system. Diversity and pioneering are the main characteristics of the electricity sector of this period (Hesselmans, 1993). At the end of the nineteenth century the discussion between AC and DC was still ongoing. Regarding the norms and values of the central government it was found that the liberal economic political paradigm in this period ruled out any major national government intervention in this new emerging sector (Vlijm, 2002). This implicated that no formal laws or acts specifically directed to electricity were adopted or effective. The national government only became involved in cases where a company asked permission for the installation of conductors near telegraph or telephone lines or along state water ways or state railways (Hesselmans et al., 2000b). There were, however, generic laws and legal issues relevant to the modernization of electricity networks. For example, next to the technical issue of DC (discussed in section 4.1.1) there were legal barriers that restricted the size of electricity networks to some hundred meters in one direction from the generation plant. The diffusion of central stations was, furthermore, hampered by institutional issues with regard to right of way, which involved the granting of a piece of land for electricity transportation purposes. This right of way was hampered by ownerships of land through or over which the cables had to be laid down. In order to implement electrical central stations, the lines and cables had to cross public roads. The institutions in place did not allow for the expansion of the system. The expansion of the system is a means to align the consumption function with the generation function of electricity and is in coherence literature regarded as strategic long term capacity management, addressing the planning of the newly to build long-living components. Concessions from the local government were needed to cross roads and they were not always willing to do so as these private energy initiatives competed with their energy supply via the gas system. From our research perspective this can be qualified as misalignment between the institutions and the function of the long term capacity management (to be further discussed in section 4.2.2). Block stations, as discussed in section 4.1.1, were easier to implement as these complied with the Steam Act[2] and the Hinder Act[3] (Hesselmans, 1993).

In this period of shifting to AC technology, institutional arrangements with regard to electricity were made between municipalities and private companies. This links to the question whether municipalities should provide electricity supply for the public interests that arose in this period. Three main directions for municipalities were followed: (1) exploit municipal generation facilities, (2) to attract the electricity from plants in neighbouring municipalities and (3) to grant concessions to private electricity companies (Verbong et al., 1998). In general, a number of municipalities regarded electricity as a competitor to their own lighting system fuelled with gas and petroleum (see Verbong, 2000). Hence, many municipalities were sceptical and reluctant to issue concessions or permissions to private initiatives with regard to electricity systems. In some cases a concession was simply not granted (Noort, 1993a) or it was granted under strict conditions.[4] These contractual arrangements between local governments and private firms resulted in low profits for the electricity companies and therewith a low interest of these private companies to be involved in electricity supply in the long run (Hesselmans, 1993). Due to the emerging idea of enlarging the scale of production the municipal companies and private companies gradually evolved into district companies. The originally municipal companies started supplying adjacent municipalities, while the private entrepreneurs established electricity companies with which to supply a conglomerate of municipalities (Hesselmans and Verbong, 2000). However, the State Commission Van IJsselsteyn of 1911 regarded the province as the most appropriate body to implement and operate the high voltage networks (Vlijm, 2002). It would take the province's permission to supply outward of the municipal boundaries. The establishment of new privately owned district central stations was therewith made impossible (Verbong et al., 1998). Scale increase and electrification was, however, still on the agenda. The national government, in their own view, would be the best actor to steer this electrification case. In 1914 the State Commission issued a report which concluded that a supra regional approach is desirable as locally organized electricity suppliers cannot meet the growing demand of electricity. In cases where the property rights were fragmented, it did not seem that simple market solutions would emerge as the provincial areas were not the most feasible areas to electrify. Around 1913 the Ministry of Water Management,[5] the government body that was at that time responsible for in electricity matters, issued permits to municipalities for the construction of inter communal connections. This happened under the condition that a higher government body could appropriate these networks. The interest of the municipalities was therewith increasingly reduced in relation to the interest of the provinces. The central government believed that electricity supply in private hands would not develop sufficiently fast as the provincial areas were not the most feasible areas to electrify (Vlijm, 2002) and everything pleaded for an instrument of the central government of a concession framework. A concession would preferably be granted to district companies, supplying several municipalities, or public companies or co operations in which these organizations had a dominating participation. This will be further discussed in section 4.2.2. The previous relates to the institutional arrangements between the government (and between the layers of government) and electricity companies. Other institutional arrangements were made between electricity companies and consumers, e.g. in the Agreement Electricity Supply[6]. Moreover, without consent and permission of the direction of the electricity company consumers were not allowed to increase the load, for example, by connecting extra electrical appliances to the electricity system (Noort, 1993b).

Logic

With regard to the logic between the institutional layers we argue that modernization of the network at the start of this period is largely coordinated at the local level. Next to small scale entrepreneurs there were a number of municipalities that stepped in the electricity sector by taking over the coordination of the municipal electricity supply. This is accompanied by institutional arrangements at the local level, i.e. arrangements of the energy company and the consumer and a number of municipal arrangements ranging from the municipal energy company and independent energy companies with a municipal concession. The role of the central government was small compared to the role of the local government. This fits with the norms and values with regard to electricity supply which was considered as a luxury good. There was no urgent need, but a more slowly emerging need to enlarge the number of electricity connections and to enlarge the supply to the Dutch households with electricity. Accordingly the institutional layers are initially aligned to a gradual bottom up expansion of the electricity network. Around 1904 the government started to consider some kind of regulation for the generation and supply of electricity (Buiter, 1994). Furthermore, the provincial concession in 1912 that followed from the central government's decree and the non-formal national concession scheme are clear indications of a central government that is reconsidering its role towards the electricity sector.

4.2 Misaligment in shifting to AC technology

In this section we discuss two major aspects of the shift from DC to AC technology in the electricity sector the need to balance demand and supply as a result of the shift to AC technology and the expansion of the electricity network enabled by the use of AC technology.

4.2.1 Balancing demand and supply

Balancing demand and supply in a DC system was partially done using local storage, i.e. batteries which could be coupled to the DC grid (Pepermans et al., 2005). However, in an AC system all produced electricity should be consumed real time.[7] In order to serve all loads the capacity of an AC central station has to meet the maximum electricity demand, e.g. by switching up or down the generating machines (Hesselmans et al., 2000b). This adaptation is a clear technical measure to cope with this new critical function referred to as balancing, or short term capacity management. It implies that most of the day, i.e. during off peak hours, a substantial amount of the installed capacity is not used (Noort, 1993b). In other words, the load factor, i.e. the ratio of the output of a power plant and the maximum output it could produce, was far below 100%. Hence, the measures that followed not only aimed at an improvement of the technical functioning of the system, but it also aimed at increasing the economic efficiency of the system.[8]
Next to a number of institutional aspects such as the ownership and control of the generation facilities a number of other important institutional arrangements were taken to safeguard the critical function of short term capacity management. First, the consumer was restricted to a maximum load as was laid down in the Agreement Electricity Supply. Without consent and permission of the direction of the electricity company consumers were not allowed to increase the load (Noort, 1993b), a typical institutional measure related to this capacity management at the consumer side instead of the generation side. Second, the management of an electricity company could reject potential consumers when they feared an extraordinary large use of electricity by a potential consumer (Noort, 1993b). A last institutional arrangement to have a better use of the installed capacity is by using a

differentiated tariff.[9] Next to the above-mentioned institutional measures there were technical measures with regard to short term capacity management in the form of more connections and connecting a more diverse set of consumers. For an energy company, a large variety of consumers would not only increase the supply but it would also spread the load better therewith increasing the load factor (Hesselmans et al., 2000b). In other words, adapting the current network to serve a substantial large number of new consumers was a technical measure to cope with this capacity management function (Noort, 1993a).

We present the process graphically in Figure 16 in which the start from DC to AC is qualified as modernization. This step has had an influence on the technical system and it, furthermore, was accompanied by the emergence of the critical function of short term capacity management, i.e. load balancing. This (foreseen) misalignment is solved by institutional and technical change. The technical change of expansion of the network as touched upon in this section is input for the following paragraph.

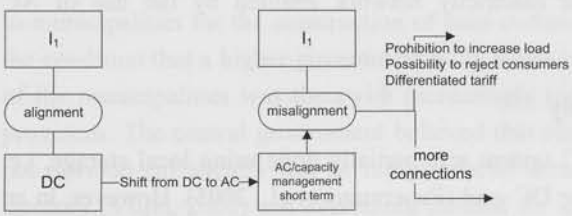

Figure 16 Relation shifting to AC and capacity management

4.2.2 Electricity networks expanding

In the 1900s a number of cities in the Netherlands were supplied with electricity. Supplying the surrounding districts became more and more of an issue, which made the AC technology more popular (Verbong, 2000). Furthermore, the desire to share generator overcapacity, qualified as capacity management, drove the adaptation of the network to serve more consumers by expansion of the network. As the scope of the capacity management increased an institution on a higher level, i.e. provincial or national level, was needed to ensure that the electricity supply would not be confined to the regions that were feasible for the existing energy companies. Institutions at the local level were inadequate to fulfill the capacity management long term at the regional level. In other words, the scope of the relevant institutions no longer matched with the expanded technical scope of the electricity system. A response to this misalignment was an institutional arrangement to safeguard the capacity management by concessions of the national government to the provinces and from the provinces to energy companies. For a new central station, of which the electricity was not for its own industrial uses and of which its supply would be beyond the (municipal) borders, a concession from the province would be required. In the decree relevant to the provincial concessions, there were certain technical conditions for the electricity system. Also the tariffs should not exceed the tariffs that a provincial company would use and small municipalities could demand a connection. It was, furthermore, explicitly stated that the decree would not hinder the provincial exploitation of electricity supply (Hesselmans et al., 2000b). Also a plan for national concessions[10] was discussed. Although the national concession scheme never became formally effective, it became a guiding principle in the electricity sector in that period. Most provinces applied for a national concession to be assured of the support of the national government in their goal of the electrification of the province (Hesselmans et al., 2000b). Within the following 10 years each province established a provincial electricity company to electrify the province. The province of Zuid Holland was a notable exception of this as this province was to a large extent already supplied with electricity by the municipal companies.

In conclusion, the capacity management long term was not supported by the institutions in place which caused misalignment. This misalignment was a driver for the institutional adaptation by a decree that gave the provinces a new role in expanding the electricity network (Figure 17).

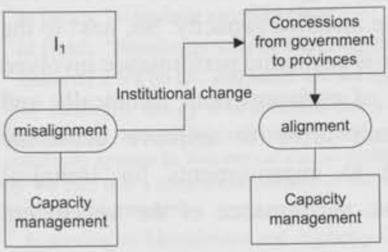

Figure 17 Relation between misalignment and institutional adaptation

4.3 Conclusions

The period 1880s-1910s is characterized as a period of shifting from DC to AC technology, a period of experimentation and pioneering. In this chapter we addressed the essential function of capacity management. Other technical functions, such as interoperability, proved to be less prominent as in this period as networks started locally as small scale individual systems and were not yet much connected to other systems. Gradually the expansion of the networks enabled by AC technology tended to combine separate systems into integrated systems by interconnection. It was noted that many interconnections started as a means to improve the technical performance, increase reliability. Subsequently it was used as a means to improve the economic performance of the system by reducing the total installed reserve capacity which led to an enhancement of the capacity utilization of the installed plants.

With regard to the logic between the institutional layers we have discussed in section 4.1.2 that modernization of the network at the start of this period was largely coordinated at the local level and at the local level it is where the institutional arrangements are found. Next to small scale entrepreneurs we found a number of municipalities coordinating the electricity supply. Compared to the role of the local governments, i.e. the municipalities, the role of the central government in this period was relatively small. This role grew bigger towards the end of the period.

We highlighted two important issues with regard to capacity management in this modernization process. First, as the system evolved from small scale local DC systems to AC systems an important technical function became critical: capacity management at operational level, i.e. load balancing. This load balancing involves the matching of the supply of electrical energy with the demand of electrical energy. This is technically done by adjusting the generation to the fluctuating demand of electricity. It was institutionally done by certain control and ownership as well as with coordinating the demand of electricity (section 4.2.1). Safeguarding this technical function is essential to avoid blackouts. The technical performance is the first priority with regard to this function and the load determines to a large extent the amount that has to be supplied to the system. This results in the installation of generation capacity that can meet the peak demand of electricity. As peak demand does not occur often, the capacity utilization of the generators is rather low and hence disproportionate compared to the total costs of the installed capacity. So, next to the technical performance that needs to be safeguarded there is economic performance involved in this essential balancing function. From the variety of measures both technically and institutionally, we conclude that there is a constant drive to improve economic performance, e.g. with a differentiated tariff, next to improvements for technical performance. More examples to improve the economic performance of the system are discussed in section 4.2.

Second, we argue that the desire to share generator overcapacity, qualified as capacity management, leads to modernization, i.e. the adaptation of the network to serve more consumers by expansion of the network. For the electrification of the rural areas the institutions in place would not suffice as the electrification would then probably be confined to the most feasible areas. We consider this a matter of misalignment, as the institutional scope no longer matches with the increased technical scope of the electricity system. That is why an institutional change in the form of a decree for provincial concessions became effective. This institutional change was both for an adequate technical system, but it gradually started to have aspects of economic performance and public value. This aspect is further addressed in Chapter 5. The main conclusions for this period are the following:

- Modernization from DC to AC is related to the critical function of short term capacity management which drove institutional and technical changes, also with regard to increasing the generation capacity utilization
- Misalignment with regard to capacity management in the long term is initiated by institutional adaptation (provincial concessions).

- The role of the central government was limited at the start of this period of modernization, but grew as the electrification of larger areas became more important.

Notes on Chapter 4

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[1] The voltage level in an AC system can be increased or decreased with a transformer. Higher voltage levels lead to significantly less losses in the transport of electrical energy, as power losses in a conductor are a product of the square of the current and the resistance of the conductor ($P = I^2R$). Since the power transmitted is equal to the product of the current and the voltage ($P=UI$), the same amount of power can be transmitted with a lower current level and an increased voltage level. Hence, it is advantageous to transport power with high voltages.

[2] In Dutch: 'Stoomwet'.

[3] In Dutch: 'Hinderwet'.

[4] In The Hague concessions were granted by the municipality at the condition that the concession could be terminated rather quickly and easily by the municipality. Many concessions were constructed in a way that private companies could hardly make any profit as large share of the electricity company's profits would be passed to the municipality. In Amsterdam concessions were given with a restricted period. After 12 years the municipality could buy the electricity company. (see also Noort, 1993a)

[5] In Dutch: 'Ministerie van Waterstaat'.

[6] In Dutch: 'Bepalingen voor de Levering van Electriciteit'.

[7] Batteries work on DC and hence are not applicable in AC systems without any conversion equipment.

[8] In coherence theory it is assumed that a certain coherence results in a performance with regard to technical functioning, economic performance and public values. Nowhere have we observed system collapses of the electricity system in this period due to problems with balancing. It is the economic performance of AC, indicated by the fact that a substantial amount of the installed capacity does not run often, that is enhanced by technical and institutional measures.

[9] According to Hesselmans and Verbong (2000) it is hard to attain a good overview of the used tariffs of this period. They do, however, find a differentiation in electricity for force and for lighting.

[10] In Dutch: 'Rijksconcessie'.

[illegible] the end of the period.

We highlighted two important issues with regard to capacity management in this modernization period. First, in the system evolved from small scale DC to AC systems as important technical function [illegible] the system [illegible] function 4.2.1). Safeguarding with temporal function is essential [illegible] technical [illegible] in the first [illegible] demand does not occur often, the capacity [illegible] hence disproportionate compared to the [illegible] technical [illegible] performance. More examples [illegible] evaluated in section [illegible]

Second, we argue that the change in these [illegible] management, leads to modernization, i.e. the adaptation of the network to serve more customers by expansion of the network. For the electrification of the rural areas the institutions in place would not suffice as the electrification would then probably be confined to the most feasible areas. We consider this a matter of misalignment, as the institutional scope no longer matches with the required technical scope of the electricity system. That is why an institutional change in the form of a licence for provincial cooperatives became effective. This institutional change was born by an adequate technical system, but it gradually started to have aspects of economic performance and public value. This aspect is further addressed in Chapter 5. The main conclusions for this period are the following:

- Modernization from DC to AC is related to the critical function of short term capacity management where there institutional and technical changes, also with regard to increasing the generation capacity and control [illegible].
- Misalignment with regard to capacity management in the long term is reduced by institutional adaptation (provincial cooperatives).

5 Electrification

In this chapter we cover the 1910s-1930s as a period of electrification of the Netherlands. We start this chapter with an elaboration of the socio-technical context of this period of electrification. Furthermore, we discuss the shift of electricity from a luxury product to a common good, local property rights hindering electrification, how electricity use was stimulated by energy companies and how interoperability gradually started to play a role in the electricity system. Additionally, we list the identified relationships with regard to alignment in the electrification of the Netherlands.

5.1 Socio-technical context

In this section we describe the socio-technical context of the period of electrification of the Netherlands. We start with a focus on specific technological aspects related to the electrification, after which we focus on specific institutional aspects related.

5.1.1 Technology

In this period of electrification an increasing number of industrial firms that were providing their own electricity supply started to buy electricity from other suppliers. There also was an increasing demand of electricity. At the end of 1913 only 180 out of 1121 municipalities[1] had electricity supply. From 1914 to 1919 many municipalities shifted their street lights from gas to electricity and in 1919 the number of electrified municipalities had risen to 405 out of 1118 (Hesselmans and Verbong, 2000). After the first world war petroleum and gas were very scarce and the demand of electricity for energy was large (Overbeeke, 2001). In other words, there was under-capacity of generation at certain regions. The Netherlands did not have hydro power or brown coal so the interconnection of the various individual electricity networks did not have great economic benefits beside the reduced need for reserve capacity (Verbong et al., 1998). Every electricity system reserves capacity to ensure system reliability. With interconnecting the electricity systems the capacity that has to be reserved is lower than the sum of the individual reserve capacities that have to be provided in case of no interconnection.

In 1910-1920 the new standard for transport of electricity over a distance of 10-20 kilometres of 10 kV was introduced in the form of a mass cable (Buiter, 1994). In the 1920s many Dutch rural areas became electrified. The provinces were leading this modernization effort (see section 4.2.2). In this decade reliable cables became available for voltage levels of 50-60 kV. The limits of the mass cable were herewith reached as higher voltages would cause problematic temperature fluctuations. In order to reach higher voltages the oil pressured cable was developed. Next to the higher possible voltage of this new cable, this type was more reliable than the mass cable with its cable isolation that deteriorates quickly under high voltages (Buiter, 1994).

In this period marketing of electricity shifted to households to expand the electricity market. Households were stimulated to buy electrical appliances (Boersma, 2006; Overbeeke, 2001). The supply of electricity rose but the cost-effectiveness of the companies was limited due to the fragmentation and the small scale generation (Boersma, 2006). A solution was found in concentration of electricity generation to make use of economies of scale.[2] Around 1930 the electrification of the major part of the Netherlands was a fact. In 1930 every household in the Netherlands was in reach of one of the 46 electricity production plants (Hesselmans et al., 2000b). The number of electrified municipalities had grown to 1011 out of 1078. In 1939 this number had climbed to 1048 out of 1054 (Hesselmans et al., 2000b). The electricity supply, however, still existed as multiple islands bounded by the provincial borders (Verbong et al., 1998). At the end of the 1930s a first high voltage (150 kV) connector was established between Rotterdam and The Hague as a means to cope with the limited expansion possibilities of the generation facility in The Hague (Zantinge, 2004). Thereafter, other surrounding provincial companies soon got interconnected (Noort, 1993a). Drivers for the interconnection were first to improve the reliability of the system and second to reduce the need for reserve capacity (Verbong et al., 2000).

5.1.2 Institutions

As more people got connected to the electricity system, the general public gradually started to value electricity as a universal service. People became more dependent on electricity and started to take it more for granted. As previously mentioned, the introduction of the Philips' half Watt light bulbs in 1913 was instrumental in turning electrical light, and therewith electricity, from a luxury product into an ordinary product for daily life (Hesselmans and Verbong, 2000). Electrification was therewith not only considered from a perspective of economic feasibility for an energy company, but also from a perspective of public utility of electricity supply (Hesselmans et al., 2000b). Availability of electricity at a reasonable price had become a prominent public value. With regard to the values or ideology of the national government, by the end of WW1 the previously adhered laissez-faire politics had vanished. The potential economic and strategic benefits of interconnected supply systems, stretching over whole regions and countries, had become a key reason for government involvement in the organization of the industry. In general the government involvement had grown with regard to the economy and labor conditions (Buiter, 1994). This was a common pattern among West European countries (Millward, 2005). In the 1920s the nature protection movement gained power. Landscape conservation had become an issue for policy makers and it was accompanied by the government's growing influence in spatial ordering (Buiter, 1994). This resulted in a clear shift from overhead to underground conductors in the low voltage network (Figure 18).

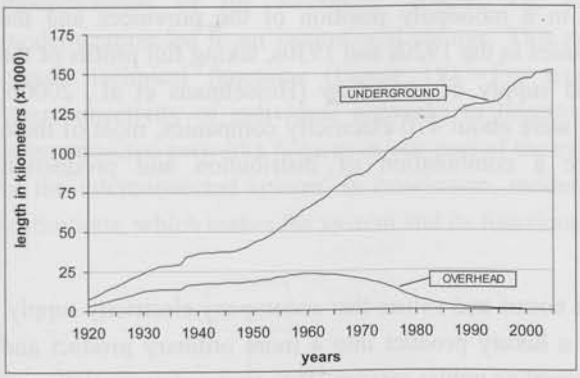

Figure 18 Total length of low-voltage electricity network 1920-2005
Data missing from 1921-1929 and 1943-1945 is interpolated
Source: EnergieNed (2007b)

Governments intervened to assure the rights of way for electrification. The Obstruction Act[3] (1918) was constructed to remove hindering institutions (Vlijm, 2002). This law made it easier for the government to coerce land owners to cooperate in the establishment of new lines (Buiter, 1994). Meanwhile the government made efforts towards a law specifically directed to electricity. It would, however, take until 1938 for the Electricity Act to be finally realized. The rural areas were at that point for a large part already electrified, foremost as a result of the provinces' effort.

By 1913 the pattern of regulation and ownership in European countries varied enormously (Millward, 2005). In the Netherlands there were provincial electricity companies, semi public limited (liability) companies,[4] municipal companies and other variations. In many cases the electricity companies were vertically integrated. However, in the rural areas there were many small scale municipal companies that only handled the distribution of electricity (Zantinge, 2004). Although the directors of the electricity companies managed their own electricity 'island', they were grouped in the Association of Directors of Electricity Companies in the Netherlands[5] (VDEN) since 1913. The VDEN was to some degree the formalization of earlier informal networks amongst these directors and a typical sector association. The VDEN was very influential and could withhold any involvement in the sector from outside (Vlijm, 2002). It would initiate a number of activities that would determine the development of the electricity supply of the Netherlands as will be discussed in section 5.2.5. Another important actor was the Ministry of Water Management which managed to gain influence by imposing permits necessary for construction of interconnections (Heuvel, 2002). In practice parties would comply with the concession framework on a voluntary basis. This was for example the case with the electricity company in Gelderland (Vlijm, 2002). There was a provincial decree of 1914 by the Gelre States. The tariffs had to be approved by the Deputy States[6]. The concession framework mandated that it was only for the provincial companies to supply customers within their provincial boundaries. This resulted in a monopoly position of the provinces and the creation of vertically integrated companies in the 1920s and 1930s, taking full profits of the generation, transport, distribution and supply of electricity (Hesselmans et al., 2000b; Stuart, 2004). By the year 1930 there were about 470 electricity companies, most of them distribution companies. Others were a combination of distribution and production companies.

Logic

The logic in this period is based on the norms and values that accompany electricity supply. In this period electricity turned from a luxury product into a more ordinary product and hence it became appreciated as a universal or public service. This renewed appreciation of electricity made large scale connections to consumers very important. On a formal institutional level we noted the Obstruction Act 1918 as a means to facilitate the electrification of the Netherlands. As the municipalities were not considered to be the most appropriate organization for electrifying the rural areas, coordination at another (larger) scale was deemed necessary (Vlijm, 2002). This fits logically with initiatives by the national government that provided concessions to provinces who subsequently provided concessions to provincial energy companies as the leading organizations in this period of electrification. In sum, the institutions complement each other in the institutional system directed at electrification of the Netherlands.

5.2 Alignment in the electrification

In this section we discuss issues related to alignment and to the electrification of the Netherlands as a modernization process. We start with a result of the expansion of the electricity network which made electricity more widely available and which changed the attitude of the general public towards electricity. Then we discuss the local institutions that hampered the expansion of the network. We, furthermore, discuss the stimulation of the use of electricity as a way to increase economic performance. Subsequently, the used electricity tariffs are discussed as these can be qualified as an institutional hindrance to electrification. We conclude this section with an elaboration of the issues with regard to the interoperability that became relevant due to the electrification.

5.2.1 Electricity from luxury product to public service

The general public gradually started to value electricity as a universal or public service. People became more dependent on electricity supply with the replacement of former kitchen appliances with electric versions and took electricity supply more for granted. The changing norms and values with regard to electricity supply were a result of the modernization of the electricity system, i.e. the electrification. In other words, modernization led to an institutional change. This resulted in an increased importance of certain technical functions (Figure 19).[7] For example, there was a new drive for interconnectivity of individual networks to improve the reliability of the system, as in interconnected networks failures in one part of the system can be supported by another part of the interconnected system. In conclusion, modernization relates to changing informal institutions, which makes the system and its functions more important (Figure 19).

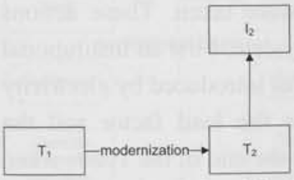

Figure 19 Changing informal institutions makes functions more important

5.2.2 Local property rights hinder expansion

In the period of electrification there were institutions, local property rights, hindering the long term capacity management, i.e. the expansion and interconnection of the network, as local property owners could block or delay important expansion efforts. In coherence terms, the institutional scope is directed at small local networks while the technical scope surpasses this institutional scope. Hence, there is misalignment in the system with regard to capacity management long term. An important formal institution to overcome such misalignment is the Obstruction Act. This act came into effect in 1918 to remove hindering institutions to electrification (Vlijm, 2002; Hesselmans et al., 2000b) and to coerce land owners to cooperate in the expansion of the electricity system. This act had a stimulating influence on the modernization of the networks. In conclusion, misalignment, i.e. local property rights and capacity management, induces institutional change (Figure 20).

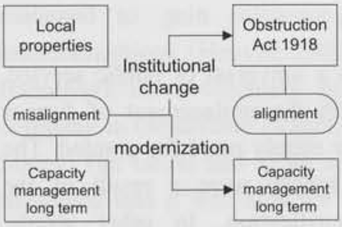

Figure 20 Local property rights misaligned with capacity management

5.2.3 Stimulation of electricity use

As mentioned in section 4.2, AC systems need to have such generation capacity installed to meet peak demand. This peak demand occurs, however, rarely. Hence, most of the capacity is hardly used, i.e. the load factor is relatively low and the capacity management function is not fully addressed. In order to reduce the installed capacity (or increase the load factor) and therewith execute capacity management several actions were taken. These actions primarily aimed at improving the economic performance of the system. First an institutional arrangement was created concerning a cheaper night tariff that was introduced by electricity companies to further stimulate electricity use and to increase the load factor and the capacity utilization (Vlijm, 2002). Another measure was taken at the end of the 1920s when the electrification of the rural areas was in full swing. Electricity companies started promoting electrical cooking and so-called night time boilers.[8] As the supply to the industry somewhat halted, electricity companies started to focus on households in order to increase the load factor. These appliances had a high electricity use and they would be used predominantly in off peak hours (Overbeeke, 2001). We qualify this action as a technical solution of implementing more loads in the total electricity system in order to use the capacity of the generation facilities more efficiently.[9] In conclusion, institutional change and technical change were measures taken to restore alignment with regard to capacity management. This was more related to increasing the load factor and therewith the economic performance, than to safeguarding the technical performance (Figure 21).

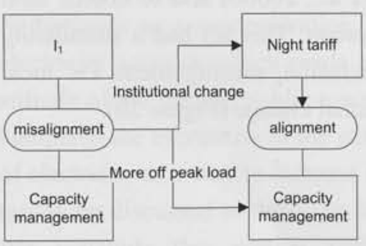

Figure 21 Institutional change and technical change to safeguard capacity management

5.2.4 Tariffs hinder modernization efforts

A second institution hindering the long term capacity management relates to electricity companies that only charged (high) variable costs, which implied uncertainty in the income to finance grid expansion. It hindered the investments to an extent that it would jeopardize a fast expansion of the network. Long term capacity management was foreseeing possible bottle necks in the capacity and acting upon this in order to align the generation capacity and the demand. The institutional measure was a change from charging high variable costs to a fixed tariff[10] and an added smaller variable component. In this way the fixed costs for the construction and operation of the electricity system could be financed (Vlijm, 2002). This had a positive influence on the modernization process. The conclusion is that misalignment with regard to the tariff structure induced institutional change (Figure 22).

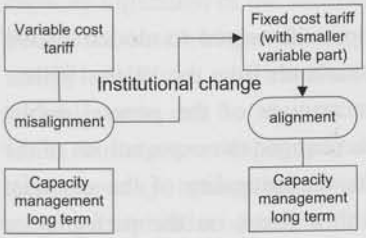

Figure 22 Variable costs misaligned with capacity management

5.2.5 Modernization relates to interoperability issues

Starting in the interwar period, gradually networks were knit together by the construction of lines between two (or more) power stations. These were interconnecting links, with power flows going in both directions. Connecting different types of power stations with their different fuels was attractive as this improved the economic mix and made the system less dependent on the fluctuations of one particular fuel. Municipal companies used their own technical standards. Within one company a standard was relatively easy to maintain. However, with the electrification and the growing number of interconnections there was a growing need for further standardization. Because of these developments the technical scope of the system increased which was to be accompanied by an increase of institutional scope. In 1922 the normalization commission of the VDEN accepted the proposed standards with regard to high voltage for the sector. In 1924 these norms came into effect (Buiter, 1994). Other institutional measures with regard to standardization that were established are the Installation Instructions[11] (1917), the Commission on High Voltage Lines[12] (1917), the Normalization Commission[13] (1917), the Safety Commission[14], the Small Plants[15] (1923), the kWh Meter Commission[16] (1926) and the Commission on Installation Issues[17] (1927)(based on Vlijm, 2002). These institutions are examples of how the interconnection of the network, e.g. modernization, relates to a need to standardize techniques and to make connections and operations compatible. In conclusion, modernization drove the possible misalignment with regard to interoperability which induced institutional change. Furthermore, the misalignment was anticipated and acted upon by the establishment of important commissions to coordinate the interoperability.

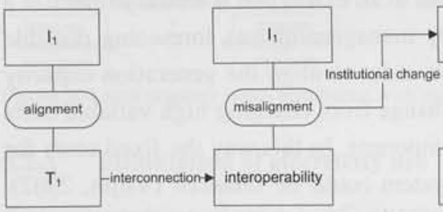

Figure 23 Modernization induces interoperability issues

5.3 Conclusions

In this chapter we highlighted some important relationships with regard to modernization and alignment in the period of the electrification of the Netherlands from the 1910s-1930s. First we pointed to how the electrification changed the attitude of the general public towards electricity and their dependence on electricity. This changed the expectations of the technical performance of electricity system and therewith the criticality of the essential functions. Electricity was until then mainly an issue with a focus on the performance aspects of technology and to some extent on economics. For example interconnections were initially established to increase reliability instead of for economic benefits. With the electrification issues the public values started to play a role. The public value of universal service obligation had a reinforcing relationship with the electrification of the Netherlands. The more people became connected, got used to it and became dependent on it, the more electricity was regarded as an inextricable part of daily life. This aspect of electricity as a universal service determined the institutional layers and its logic for a large part in this period of electrification (discussed in section 5.1.2). The universal service aspect of electricity made the initiative of connecting the electricity system to potential consumers ever more urgent resulting in e.g. the Obstruction Act 1918. The national government provided concessions to provinces therewith providing them with the assignment to electrify the rural areas. The provinces on their turn provided concessions to provincial energy companies as the leading organizations in this period of electrification. The institutional layers have thus a logical fit in stimulating and facilitating the electrification of the Netherlands.

Second we discussed the local institutions that hampered the expansion of the network and that was reacted by the central government with the Obstruction Act 1918. The central government had a facilitating role and only intervened when there was a problem that could not be solved adequately by the other actors in the electricity sector. With regard to the different institutional layers we argue that the role of the central government was thus limited. Although the central government had a role in the electrification of the rural areas by granting concessions to the provinces it was the provinces that led in the electrification. This is remarkable for an infrastructure that seemed potentially very important for the whole of the Netherlands. This ordering of the electricity sector by provinces was the exception in Europe. In most other European countries it was the national government that became leading in the electricity supply[18] Additionally, it were coincidental circumstances that made provinces take the lead in the electrification. If the provinces would have come a few years later with their electrification plans the national government would probably have intervened. (Hesselmans et al., 2000b).

Third we elaborated on the stimulation use of electricity by the electricity companies as a way to increase economic performance. A number of generators were installed in order to cope with the increasing peak demand that resulted from the electrification. The stimulation of electricity use was a measure in order to generate extra income and to increase the capacity utilization of the installed generators.

Fourth we observed that the modernization is influenced by the economic performance of energy companies which is also related to the electricity tariffs used. Charging only (high) variable costs can be an institutional hindrance to the expansion of the network, which refers to long term capacity management. In other words, the essential function of long term capacity management was not safeguarded with the institutions in place. This misalignment induced an institutional change to a fixed cost tariff in order to cope with the capacity management long term adequately.

Fifth interoperability that became relevant due to the electrification effort. We observed that a large number of standardization commissions emerged from the electricity sector that became relevant due to the numerous interconnections that were established as a result of the electrification. In order to maintain the technical integrity of the system the different elements of the system need to be technically aligned. This was the task of these interoperability and standardization organizations. This essential function had to be aligned to safeguard the performance of the system as a whole. The interconnection was driven by the need for a more reliable system and the desire for the electricity companies to flatten out electricity peaks and therewith increase the capacity utilization of the installed generators. In sum, the following observations are made:

- Changing public values made the electricity system as a whole and its technical functions more important.
- Misalignment with regard to capacity management and local property rights drove institutional change with regard to the Obstruction Act.
- Misalignment with regard to capacity management and variable costs tariff arrangements was followed by institutional change.
- The misalignment with regard to interoperability as a result of modernization, i.e. the electrification, was foreseen and anticipated upon with institutional change (standardization commissions).

- As an exception in Europe it was not the central government but the provinces that led the electrification of the Netherlands.

Notes on Chapter 5

[1] Meer and Boonstra, 2006

[2] Concentration of electricity generation needed to be done gradually in order to avoid capital destruction (Buiter, 1994).

[3] In Dutch: 'Belemmeringswet 1918'.

[4] In Dutch: 'Naamloze Vennootschap'.

[5] In Dutch: 'Vereeniging van Directeuren van Electriciteitsbedrijven in Nederland'.

[6] In Dutch: 'Gedeputeerde Staten'.

[7] This shift in criticality is an exception to other examples of relationships between the main concepts in our conceptual framework.

[8] In Dutch: 'Nachtstroomboilers'.

[9] This example is one of modernization of the whole electricity system rather than modernization of the electricity network.

[10] In Dutch: 'Vastrechttarief'.

[11] In Dutch: 'Installatievoorschriften'.

[12] In Dutch: 'Commissie voor Hoogspanningslijnen'.

[13] In Dutch: 'Normalisatiecommissie'.

[14] In Dutch: 'Beveiligingscommissie'.

[15] In Dutch: 'Kleine centrales'.

[16] In Dutch: 'kWh metercommissie'.

[17] In Dutch: 'Commissie voor het installateursvraagstuk'.

[18] Notable exceptions were Denmark and Norway.

6 Interconnection and reinforcement

In this chapter we address the socio-technical context of the period from the 1940s to the 1970s characterized by interconnection and reinforcement of the electricity system. We discuss the state of the electricity system and the trends relevant to this period of interconnection and reinforcements. In the subsequent section we combine the technological and institutional view. We first address the inadequate generation capacity after which we analyze under which conditions technical functions became critical and how this criticality was coped with institutionally and/or technically. Furthermore, we list the identified relationships between the interconnection/reinforcement and alignment.

6.1 Socio-technical context

In this section we elaborate on the specifics of the socio-technical context of the modernization process of interconnection and reinforcement. We first focus on the technological trends relevant to this modernization effort, after which we address the institutions that were relevant to modernization in this period.

6.1.1 Technology

Despite the meshed electricity network consisting of overhead lines the overall electricity supply in the Netherlands in the 1930s comprised of separate electricity islands bounded by provincial borders. There was a the lack of integration of existing provincial networks (Verbong et al., 1998). Due to this, electricity companies had a disproportionate large reserve capacity. Also the financial and spatial issues with regard to new generation plants within the provincial borders resulted in necessarily broadening of the interprovincial view. The technology of high voltage lines was ready for this supra provincial approach (Vlijm, 2002).

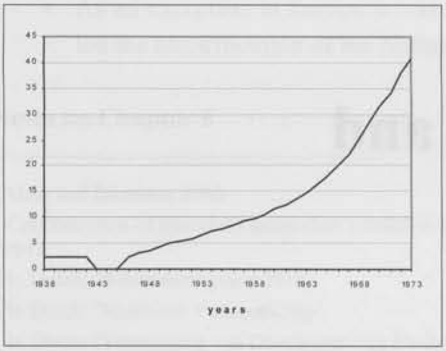

Figure 24 Total electricity use (TWh) 1938-1973
Source: EnergieNed (Vlijm, 2002), for the years 1929-2005 we refer to Appendix B.

After WWII parts of the infrastructure were damaged and in need of repair. There was considerable shortage of materials (Vlijm, 2002). This implied that supply of electricity could not always meet demand. This problem was enlarged by the growing electricity use. In 1950 the electricity use had doubled compared to 1940. At the end of the 1950s we see an increase in demand and from 1965 to 1973 a growth of demand of 10% per year is witnessed (see Figure 24). The network could hardly cope with the growing supply and load (Vlijm, 2002). Due to the pressing need for transport capacity as a result of the industrialization and the railway electrification there was a strong drive to build new lines and sub stations. In LTS terms (section 2.4.1) these parts of the system would be considered reverse salients. This connection grid, i.e. the provincial coupling network, was to be finalized in the 1950s.

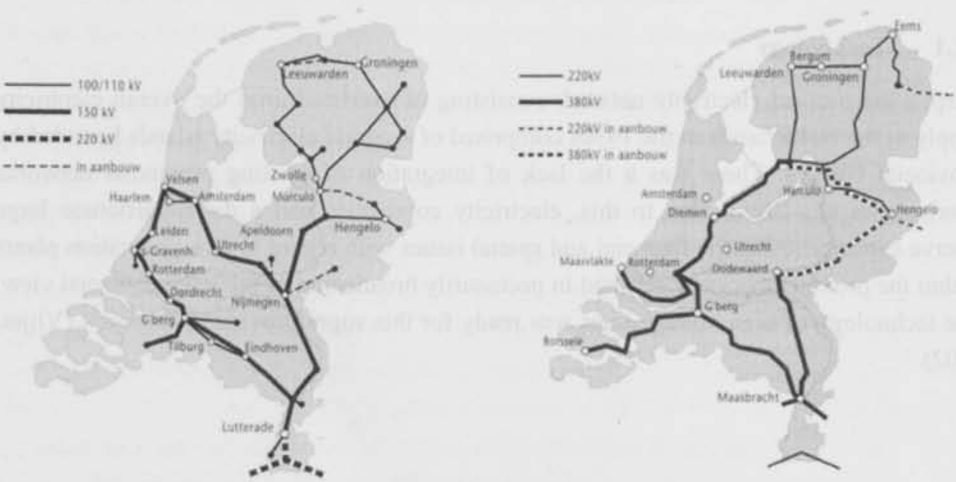

Figure 25 Coupling network in 1954 (left) and second coupling network in 1981 (right)
Source: Hesselmans et al. (2000a)

In 1950 the major electricity plants of the provinces of Limburg, Noord-Brabant, South - and North Holland were connected and in 1953 all Dutch centralized electricity plants were connected (see Figure 25). The role of this interconnecting network was foremost to serve as emergency backup (i.e. for the reliability or the technical performance of the system, although sporadically agreements were made for interregional electricity exchange (i.e. for the economic performance of the system).[1]

The growth of electricity demand in the 1960s and 1970s was acted upon by network reinforcements and interconnection (Noort, 1993a). In this period more and more focus was on economies of scale in generating electricity. The price and costs of electricity dropped due to technological developments and the trend was to build ever larger and economically more efficient generation facilities. (Overbeeke, 2001). The construction of this high voltage network continued in this period in order to cope with the larger currents and higher voltages, and in 1969 the establishment of the 220 kV and the 380 kV lines started as being the second coupling network. This status of the second coupling network after this period of interconnection and reinforcement is presented in Figure 25. The prime driver for this modernization was to increase the reliability of the electricity system.[2] In case of a potential blackout other generation plants could help with their reserve capacity to make supply meet demand. However, we also identified a clear economic component in the performance outcome of these measures, since the overall reserve capacity could be reduced due to these interconnections. As the networks grew bigger and more interconnected technical problems arose such as cascading effects in case of frequency and voltage deviations and blackouts. Generation facilities were built at a larger distance from consumers resulting in a higher transporting voltage. Failures of a big generation facility needed to be backed up by a reserve capacity that was in proportion to that facility. Since this reserve capacity had to be able to reach the area of the failure, also the capacity of the lines had to be able to accommodate that amount of electrical energy with such high a voltage (Zantinge, 2004). We refer to the critical functions that were relevant to these developments in section 6.2. Due to the increase of electrical energy over these connection lines problems with regard to reactive power emerged. This will be addressed in the following section. The introduction of the 380 kV conductors in 1969 resulted in physical problems with tension safeguarding. Higher tensions of high voltage lines and the tension loss due to generation of reactive power in neighbouring plants would cost more efforts to keep the voltage at the right ievel (Zantinge, 2004). We also discuss this in section 6.2.

6.1.2 Institutions

Electricity had become widespread in this period. Electric appliances had become more and more standard in households. With the diffusion of household appliances the dependence on electricity had grown among households. This was an important aspect in the public values towards electricity. Regarding the attitude to electricity for the Netherlands as a whole we argue that the self sufficiency of the country was considered more important due to the experience of WWII (Heuvel, 2002). The period after WWII was one of rebuilding the Netherlands, in which the central government had an important role also with respect to the distribution of scarce goods. The public value of reliability and affordability of the electricity played an important role in this distribution. However, in the electricity sector the role of the national government remained rather limited. It was only in the 1960s that the national government became discontent with its relatively small role in the electricity sector (Verbong and Geels, 2007). Vlijm (2002) lists three main factors for this development: first, the discovery of the enormous gas stock in the Netherlands; second, the report on the Limits to Growth (Meadows et al., 1972); and last, the oil crisis of 1973.[3] Improving the economic performance of the electricity became more and more a permanent goal in the electricity sector. Whereas coupling lines were initially implemented to meet the public value of security of supply and reliability, gradually economic aspects became prominent in the daily operation of the electricity system. This resulted in a number of cost efficient measures of which the central dispatch of generation facilities was a very prominent one (further explained below).

A first important formal institution is the Electricity Act of 1938 in which the central government attained influence on the electricity supply by means of licenses for electricity suppliers (Heuvel, 2002). This is a clear sign of the national government aiming at a larger role in the sector's development. Another important formal institution with regard to electricity was the Price Raising and Hoard Law[4] of 1939: prices of products and services were not to be raised without permission by the central government, the minister of Economic Affairs.[5] In 1945 the Price Regulation Electrical Energy[6] was installed and in 1951 there was a principal revision of the price politics with regard to electricity tariffs on basis of cost price and rate of return, with the fuel prices as the main ingredient of the total electricity costs. The costs for the electricity companies were disproportionate to income with the tariffs in place (Vlijm, 2002). Furthermore, the central government prohibited the financing of provincial electricity companies by the provinces. The necessary expansion of the electricity system to stimulate economic recovery and the scarcity of the capital market were impulses for a new electricity policy. In 1952 a new Price Regulation Electrical Energy came into effect (Vlijm, 2002). This implied that the economic cost price determined the electricity tariff, the tariff per kWh. The right to increase the tariffs allowed for the use of more internal sources instead of external financial sources.[7]

Until WWII there was no real collaboration at daily operational level in the electricity sector between the electricity companies (Vlijm, 2002), as the networks where not yet technically interconnected. There have, however, been a number of informal institutional arrangements between energy companies made by the directors of the electricity such as the VDEN, as previously addressed. The VDEN was very influential and could withhold any involvement in the sector from outside (Vlijm, 2002). This VDEN might have contributed to resolving certain technical problems. Before WWII the most important parties agreed upon establishment of two closed rings that were interconnected. With this up scaling of the network and increase of the technical scope, an institutional change might be required (further elaborated in section 6.2.2). During WWII the basis was, therefore, laid down for a more corporate discussion platform, which is a clear distinction from the pre-war period (Verbong et al., 1998). Around 1940 many provinces had their provincial electricity companies that operated the provincial electricity system. In 1942 Van Staveren, as chairman of the group of electricity companies with the assignment to reorganize the electricity sector, published a report in which cooperation was foreseen between provincial electricity companies connecting across provincial borders, either voluntarily, or by intervention of the central government (Verbong et al., 1998). The biggest part of the budget for the connection of networks was to come from the electricity companies. These companies were assumed to cooperate under guidance of the government. An important barrier to the establishment of the interconnection grid was the refusal of provincial electricity companies to move responsibilities to an overhead body. This issue played a role in most negotiations and the construction of interconnecting lines was the biggest hindrance in the establishment of, for example, the Electricity Company South Holland[8] (EZH) (Verbong et al., 1998). In 1941 the EZH was finally established when six municipal companies of South Holland agreed on provincial collaboration, which could be persuaded due to the remaining autonomy for the participants in the institutional arrangement. Hence, this collaboration should be qualified more as a contractual agreement than as a real merger. The municipal companies remained responsible for the production and distribution of electricity in their own region. EZH gained control over the connecting lines and the exchange of electricity between the central stations. A similar institutional arrangement was *mutatis mutandis* used for the establishment of the Collaborating Electricity Production Companies Ltd.[9] (SEP) in 1949, the institutional arrangement in which the existing companies handed over a minimum of their responsibility (Vlijm, 2002). The SEP was established to stimulate collaboration in the sector and consisted of the provinces of Friesland, Groningen and North Holland, the municipality of Amsterdam, the NV Provincial and Municipal Utrecht Electricity Supply, the NV Electricity Company South Holland, the Twentsch Central Station for Electrical Current Supply, the NV Ijssel Central Station and the electricity companies of Limburg, Noord Brabant and Gelderland (Vlijm, 2002). The SEP would coordinate the electricity production. Most of the technical issues were described in the articles of the SEP. The interoperability was safeguarded by setting technical standards (further discussed in section 6.2). Technical issues with regard to generation of electricity and the transport of electricity were also centrally coordinated. In 1970 eleven production companies and the SEP signed a General Agreement of Collaboration to intensify the collaboration with regard to electricity production. Furthermore, it would formulate the national plan of electricity expansion with a yearly Capacity Plan (Vlijm, 2002). As mentioned previously, a gradual shift was observed from a focus on the technical aspects to the economic aspects of the electricity system. Although the reinforcement and interconnections were foremost executed to increase the reliability of the system, we also identified a clear economic component in the performance outcome of these measures, since the overall reserve capacity could be reduced due to these interconnections. Furthermore, with an interconnected system it was also possible to dispatch the cheapest generators to reach a more cost efficient overall performance. In 1976 there was a collaborative effort in the south of the Netherlands with regard to central dispatch of electricity plants called the Southern Economic Optimization (ZEO)[10] (Vlijm, 2002). In this collaboration the generation facilities would be dispatched which have the least marginal costs. In 1981/1982 a new program was implemented for a National Economic Optimization[11] (LEO).

Logic

In this period the institutional arrangement of the SEP played a key role. This role was in line with the informal institutions of universal service, rebuilding of the Netherlands, economies of scale and the reinforcements and interconnections of the electricity system. Although there was an Electricity Act 1938, the role of the central government was rather limited compared to the SEP with regard to the modernization of the electricity system. However, there were quite a number of national government laws and regulations that were in line the rebuilding of the Netherlands, the scarcity of electricity and the universal service. The role of the central government changed in the 1970s when the norms with regard to energy changed. In the 1970s, the energy sector was gradually seen as a crucial sector for the whole economy and a sector that the national government should get more and more involved in. Despite a number of national committees that explored the future organization of the electricity sector, most technical issues where determined at sector level by the SEP. Furthermore, the SEP in this period grew in importance as it gradually incorporated more and more important elements and functions of the electricity system (as elaborated above). In conclusion, the institutions at different layers were directed at interconnecting and reinforcing the electricity system. This was initially done for reliability reasons, but gradually the economic aspects started playing a role, which for example resulted in more regular transport of electricity over the interconnection lines than was initially foreseen and other economic initiatives such as the national economic dispatch of generators.

6.2 Alignment in interconnecting and reinforcing the system

In this section we discuss a number of important alignment issues with regard to interconnection and reinforcement of the electricity networks in the Netherlands. First we elaborate on the lack of electricity generation from a shortage of fuel, which was followed by an impulse to make extra interconnections in the electricity system. Second we address the critical functions that are involved in reinforcements and interconnections and the way that these functions were coped with.

6.2.1 Generation capacity inadequate

As noted in section 6.1.1, at the start of this period the electricity system was rather inefficient as every separate electricity system maintained its own reserve capacity (Verbong et al., 1998).[12] Furthermore, the electricity production was hindered by the coal shortage. As generation capacity did not align with the other parts of the value chain such as the network part and the consumption we qualify this situation as misaligned with regard to capacity management. A number of institutional and technical adaptations were made in the years that followed. In 1941 electricity became under ration (Verbong et al., 1998; Vlijm, 2002), an institutional measure to align generation capacity with consumption. In 1947 a shift in working hours was introduced in the industry as a means to avoid a complete overlap with the households' electricity demand pattern (Vlijm, 2002), which implicated that peak load would decrease. Furthermore, in 1951 it was again necessary to take measures to cope with the peak load just as in the years before. The industry was very willing to cooperate on a voluntary basis. For stores the previous method was revised and the companies that voluntarily participated were to cap the electricity use using only half of the installed capacity. Commercial lighting was prohibited during peak hours and radio broadcasts stopped during peak hours. (Vlijm, 2002).[13] All of these institutional adaptations were made to manage the limited electricity supply and to make efficient use of the available capacity. Furthermore, institutional measures were taken such as the Price Regulation Electrical Energy that would better enable the expansion of the electricity system (see section 6.1.2). Additionally, there were technical measures to cope with the capacity management, for example, by modernization of the network and therewith aligning the network capacity and the generation capacity with the consumption. The government stimulated the building of electricity transport networks to accommodate the transport of electrical energy from the mining areas to the main loads of the Netherlands (i.e. the West and the South) to facilitate the supply meeting the demand of electricity and to minimize the overall reserve capacity. A conclusion that can be drawn is that the misalignment with regard to the capacity management function was responded with modernization through extra connections of the network and by institutional arrangements to reduce the peak demand of electricity (Figure 26).

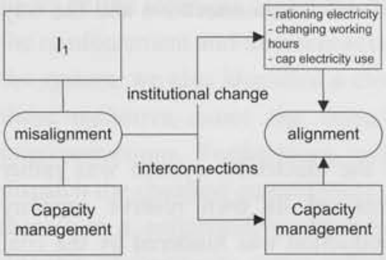

Figure 26 Reduced generation capability misaligned with capacity management

6.2.2 Modernization increases critical functions' importance

With the modernization of the networks by reinforcements and interconnections a number of critical functions with regard to the interdependency of the capacity management and the accompanying cascading effects became more important. The SEP can be regarded as the institutional coordination body to cope with the increasing technical scope of the electricity system. Issues that relate to the tasks of the SEP in 1949 are the following: the daily care of sufficient production in plants of the members, the coordination of revision and maintenance of generators and parts of the coupling network, making coupling networks available; the calculation of a total need for installed capacity based on previous failure statistics and making available reserve production capacity. Furthermore, with regard to national interconnection (modernization) of the networks there was a potential misalignment with the different standards and routines that were used for the installations which were tackled by the SEP. Although a number of technical issues have been taken care of in earlier standardization commissions and documents, a number of issues were still to be determined by the individual electricity companies themselves. With this enlargement of the technical scope of the electricity system to the national level the institutional scope, among other things for coordinating standardization, should be enlarged as was being done by establishing the SEP.

The large number of interconnections that were established prior to and after WWII transformed the previous electrical islands into a big interconnected system. The resulting institutional measure was the capacity planning of electricity plants and transmission lines which was coordinated with a Capacity Plan (Zantinge, 2004). From 1950 onwards the SEP made an Electricity Plan for the next 10 years[14] in which the building of electricity plants was coordinated with the transport function.[15] The SEP decided whether and how new plants had to be build in order to make supply meet demand (Vlijm, 2002).

The generation facilities were built with increasingly large capacities and at larger distances from consumers than before. This was in line with the economies of scale paradigm that was prominent in the sector at this period. The larger distances were accompanied with a higher required transporting voltage. In case of a failure these bigger generators needed to be backed up by proportionally big reserve capacity that should be able to reach the area of the failure. This implicated that also the lines would need the capacity to accommodate that amount of electrical energy (Zantinge, 2004). We qualify this as capacity management by the alignment of the transport with the generation capacity of the system. Due to the bigger generation facilities and the foreseen misalignment with regard to capacity management modernization of the network had to occur. We conclude that larger generation plants were accompanied by the reinforcements of the system as a long term capacity management measure. As addressed in section 2.4.4 this example also relates to the LTS literature in which the technological environment of a reverse salient (i.e. the electricity lines) in the large technical system can be an important driver to technical change. In LTS terms it can be seen as technical alignment of the system, in coherence literature terms it can be seen as strategic long-term capacity management addressing the planning of the newly to build long-living components.

The prime driver for the 220 kV and the 380 kV connector lines was to increase the reliability of the electricity system.[16] The modernization of the network by construction of the national coupling lines of 380 kV that started in 1965 had significant implications on the voltage control. At higher utilization of the high voltage lines and the accompanying voltage losses should be compensated by reactive power in neighbouring plants.[17] It, however, takes more effort to keep the currents at an optimal level (Zantinge, 2004). The long lines and cables with a high voltage form a capacity to the earth, which makes the phase of the voltage to a certain extent lag behind the phase of the current. This is largely offset through the load that is mostly inductive and which makes the phase of the current lag behind the phase of the voltage and therewith compensates for the capacity, i.e. the capacitive load. However, at low demand periods (e.g. in the week end) the capacity of the high voltage transmission lines is very dominant. This results in higher tension and an accompanying need to control this tension. Furthermore, the capacitive load is unfavourable for keeping the generators of the electricity plants stable. As a measure in weekends in some high voltage stations the so called shunt reactor[18] is operated parallel to the load, which results in an acceptable value for the capacitive reactance.[19] This was institutionally coordinated by the SEP by requests of generators for reactive power compensation. We conclude that modernization of the network by implementation of 380 kV conductors relates to misalignment. This misalignment subsequently relates to institutional change as it was safeguarded by the SEP.

Many other measures were undertaken by the SEP to improve the reliability of the system. In the first half of the 1960s there was a focus on reliability by SEP, and in international context by the Union for the Co-ordination of Production and Transmission of Electricity (UCPTE). An institutional measure was the implementation of disconnection instructions by the SEP to avoid the increase of certain blackouts (1960-1965). As a technical measure electrical installations of the plants by SEP would be improved to avoid drops in the network with at large fluctuations of electric tension and frequency (Zantinge, 2004). Another technical measure relates to the automatic minimum frequency relays that were introduced with uniform settings in the networks. In case of a frequency drop that part of the electricity network is disconnected in order to avoid a frequency drop in the whole system. Another issue relates to the short term capacity function (balancing). In the mid-1960s, electric utilities adopted gas turbines for peak-load generation and emergency supply, in response to power blackouts that occurred when demand exceeded supply. These interruptions were foremost the result of a disturbance in the high voltage network that influenced the power supply in the generation plants which subsequently broke down (Hesselmans et al., 2000a). A gas turbine is very suitable for short term capacity management as the time to adjust the power output of a generator is significantly shorter than that of, for example, coal fired power plants. The situation at hand is one in which misalignment was not anticipated but acted upon when blackouts already occurred. The short term capacity management is restored by the adoption and use of the gas turbines as a emergency back up facility (Hesselmans et al., 2000a). In conclusion, foreseen misalignment (new system functions and current institutions) induced modernization of the system and institutional change. Furthermore, misalignment – current institutions and capacity management short term – relates to modernization of the system by means of the application of the gas turbine. That restored the technical performance of the system (Figure 27).

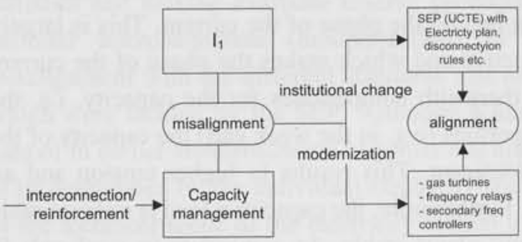

Figure 27 Relation of modernization and SEP as coordination body

6.3 Conclusions

In this chapter we discussed a number of important issues relevant to the alignment with regard to the period characterized by reinforcement and interconnections.

With regard to the logic we found that the institutional arrangement of the SEP played a key role in this period. This role was in line with the informal institutions of the electricity system with regard to the universal service of the electricity and with the general objective of a more reliable interconnected and reinforced electricity system. Although there was an Electricity Act 1938, the role of the central government was rather limited compared to the SEP with regard to the modernization of the electricity system. However, a number of national government laws and regulations came into effect. In the 1970s the role of the national government became more prominent in the electricity sector although still most technical issues where determined by organizations within the electricity sector. There is a logical fit of institutional layers in being directed at the reinforcement and interconnection of the system.

First we elaborated on the lack of electricity generation from a shortage of fuel, which was followed by a drive to make extra interconnections and reinforcements in the electricity system. We identified a number of institutional measures to cope with this situation, such as rationing regulation and rules with regard to changing working hours. After WWII we see a relatively large role for the central government in the capacity management with regard to this misalignment issue. For example, next to rationing laws, the national government was involved in the regulation of financing of provincial energy companies in 1951. The central government facilitated this effort by allowing electricity companies the right to increase the tariffs. Furthermore, the national government stimulated the building of electricity transport networks to accommodate the electrical energy from the mining areas to the large concentration of demand in the west and the south of the Netherlands. This intervention by the national government after WWII is in line with the atmosphere of rebuilding the Netherlands. Whereas in the previous period of modernization the provinces were the leading actors, in this period the provinces were holding on much to their powers by refusing to move responsibilities to an overhead body, i.e. the SEP. This was more a barrier than a driver to the modernization effort in this period (Verbong et al., 1998).

Second we addressed the critical functions that grew in importance due to the reinforcements and interconnections. An important issue in this period is the establishment of the SEP, the organization that safeguarded a number of important technical functions. At first instance, the tasks of the SEP were largely to safeguard the technical performance of the system, to coordinate the match between the implementation of production and transport capacity and to fulfil important public values such as safety and affordability. The aggregated performance of the electricity system was a trade off of these elements. We observed, however, a shift in this trade off from a focus on the technical aspects to the economic aspects. The reinforcement and interconnections were foremost done to increase the reliability of the system. In case of a potential blackout other generation plants can help with their reserve capacity to make supply meet demand. However, we also identified a clear economic component in the performance outcome of these measures, since the overall reserve capacity could be reduced due to these interconnections. Furthermore, in 1981/1982 the National Economic Optimization was introduced. The dispatch of the generators, based on the least marginal costs, would be coordinated centrally from Arnhem (Noort, 1993b). For this period we conclude the following:

- The misalignment with regard to capacity management, i.e. the mismatch of generation and consumption, was responded with modernization through extra connections of the network and by institutional arrangements which reduced electricity peak demand.
- As a consequence of the modernization of the network by reinforcement and interconnection a number of critical functions grew in importance with regard to the

interdependency of the capacity management and the accompanying cascading effects.

- The SEP can be regarded as the institutional coordination body to cope with the increasing technical scope and the new critical functions of the electricity system as a result of the modernization by reinforcements and interconnections of the system.
- Larger generation plants were accompanied by the reinforcements of the system as a capacity management measure, which can be qualified as a technical alignment.
- (Foreseen) misalignment as a result of modernization (new system functions and current institutions) induced modernization of the system, e.g. installation of frequency relays and gas turbines, and institutional change, e.g. Electricity Plan and disconnection rules.
- Modernization with interconnections and central dispatch relates to better capacity management as a means to improve the economic performance of the system.

Notes on Chapter 6

[1] The possibility of load dispatch to produce electricity with the generation facility with the least marginal costs at a national scale was not yet an issue as the initial purpose of the provincial lines was to serve as emergency backup (Verbong et al., 1998).

[2] Interview with NET07, held August 2, 2006; Interview with SUP03, held August 4, 2006; Interview with NET08, held August 9, 2006

[3] There was, for example, an agreement of the the national government and the SEP in 1975 in which the SEP was obligated to submit its period electricity plan to the minister of Economic Affairs for approval.

[4] In Dutch: 'Prijsopdrijving- en Hamsterwet'.

[5] The Ministry of Economic Affairs had become the ministry to manage issues with regard to electricity

[6] In Dutch: 'Prijzenbeschikking Elektrische Energie'.

[7] "The depreciation costs in the cost price were to be calculated on the basis of the replacement value of the company active and the interest of the capital with an interest rate of 5%. The extra income as a consequence of the increased tariffs were to gain extra finances for the extensive expansion of the company, especially production" (cited from Vlijm, 2002)

[8] In Dutch: 'N.V. Electriciteitsbedrijf Zuid-Holland'.

[9] In Dutch: 'N.V. Samenwerkende Elektriciteit Productiebedrijven'.

[10] In Dutch: 'Zuidelijke Economische Optimalisatie'.

[11] In Dutch: 'Landelijke Economische Optimalisatie'.

[12] The plans for the interconnection grid were there, but there was no realization yet.

[13] From 1952 on these measures were not considered necessary anymore (Vlijm, 2002).

[14] According to LAKA, 2008 it was an annual plan for the coming nine years.

[15] Interview with NET07, held August 2, 2006.

[16] Interview with NET07, held August 2, 2006; Interview with SUP03, held August 4, 2006; Interview with NET08, held August 9, 2006

[17] Potential instability problems can also occur at 110 and 150 kV cables, of which there is about 6000 kilometer in the Netherlands. But here these are under control. The higher the tension, the more difficult to remedy reactive power, according to Blom, professor of electrical energy technology (Tolsma, 2008)

[18] In Dutch: 'Laadstroomcompensatiespoel'.

[19] Such a shunt reactor is a field winding with a very small resistance but with a large inductance. This results in a high reactive idle power. In the 380 kV station of the high voltage networks the shunt capacitors are implemented with a reactive idle power of 50 MVAr.

[illegible]

- [illegible] technical [illegible] as a result of the [illegible]
- Larger generation plants were [illegible] capacity management approach, [illegible]
- [illegible]
- [illegible]

Notes on Chapter 6

[illegible]

In Dutch: [illegible]

[illegible]

In Dutch: [illegible]

[illegible]

In Dutch: [illegible]

In Dutch: [illegible]

In Dutch: [illegible]

In Dutch: [illegible]

[illegible]

Interview with [illegible]

[illegible]

In Dutch: [illegible]

7 Shift to a hybrid system

In this chapter we address the period since the 1970s until present characterized as a shift to a hybrid system consisting of both centralized and decentralized generation facilities. In the section on the socio-technical context we address the rise of distributed generation and the developments regarding liberalization of the electricity sector. With regard to this latter development we pinpoint to a number of critical functions that needed to be safeguarded in a liberalized electricity system. Additionally, we discuss a number of alignment issues in this period of shifting to a hybrid system. First, we address the power quality as a result of distributed generation. Second, we address the misalignment as a result of (international) interconnections. Finally, we list the identified relationships between this shift to a hybrid system and alignment.

7.1 Socio-technical context

In this section we address the technical developments of the socio-technical system in this period of shifting to a hybrid system. We describe the relevant institutions that accompany this shift to a hybrid system. A special focus is on liberalization which involved the abolishment of the SEP. We highlight this aspect as this relates to a large number of issues with regard to alignment and the safeguarding of the essential functions of the electricity system.

7.1.1 Technology

Although in the 1970s and 1980s the economies of scale paradigm was still prominent for the generation and transport of the electricity system, the 1990s show a clear deviation from the economies of scale paradigm (see Figure 3). This development started around the 1970s when the idea gained ground of relatively small sized generators with close proximity to the load. Figure 28 shows the start of the implementation of CHPs and the enormous rise of decentral electricity production in the 1980s and 1990s as a result of different government measures (elaborated in section 7.1.2). In 1990 the decentralized capacity was 2.1 GW, a figure which doubled in 1995 (Brunekreeft, 1997). This will be further discussed in section 7.2.

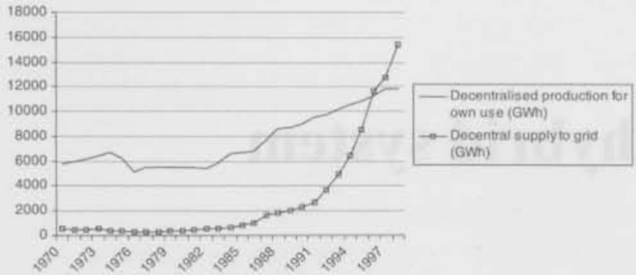

Figure 28 Grid supply and own use of decentralized electricity
Source: Based on data from Rob Raven on the basis of several SEP reports (Verbong and Geels, 2007)

Recent years have seen a sharp increase in the use of solar and wind power, gas turbine technology, combined cycle technologies, fuel cells and the like (Ackermann et al., 2001; Pepermans et al., 2005), resulting in a number of power quality issues[1] like impulsive transients, voltage sags, flicker, harmonics, imbalance, and frequency control problems (Kundur, 2004).[2] This is further discussed in section 7.2. Other recent issues that are relevant for the technological system are issues such as the ageing assets of electricity network components and smart meters. Smart meters can be considered as a technical measure at the consumer side of the network as a first step towards real time monitoring of electricity use and costs. If the costs are real time represented, it can be an impulse for consumers to refrain from using an energy intensive household appliance at that very instant as this would involve a relatively high cost per kWh. This (aggregate) behaviour would flatten the peak load.[3]

Another issue at the consumer side is raised by Mr. Mihály Antal, the chairman of the research program Innovation Development Projects Electromagnetic Power technology (IOP-EMVT)[4], who stresses that a current problem of the large and increasing number of consumer and industrial appliances such as battery loaders that pollute the network by lowering the quality of the tension and frequency (SenterNovem, 2004). Lighting installations in horticulture, for example, cause third harmonics and thus reduces power quality. This can be technically resolved by using filters.[5] Another current trend is LED lighting which has a capacitive impact and hence can become a clear problem.[6] Norms are a possible institutional solution for this. This 'pollution' of the electricity system by capacitive and inductive loads is an issue since the norms and expectations of the electricity supply are currently higher than ever. Without this criticality laptops and other electronic devices would not function properly as these are more sensitive than previously: 0.8-1.15 of nominal tension.[7 8]

Next to the relatively recent paradigm of distributed generation the former paradigm of economies of scale still holds. We observe clustering of generators in big plants and the drive for larger interconnected markets (Verbong and Vleuten, 2004). In general, interconnection in Europe is growing and will be growing in the near future, together with the DG trend resulting in a hybrid system.

7.1.2 Institutions

The public value of affordability and reliability of the system are prominent in this period. The economies of scale paradigm still held in this period and contributed to increased economic performance and affordability. The interconnections and reinforcements of the system were mainly to drive the reliability of the system. The economies of scale paradigm was also an important driver in the reorganization of the electricity sector, as will be further discussed in this section. Initiated by the oil crisis and alarming reports on the finite character of fossil fuels,[9] in the 1970s attention was drawn to more environmental friendly electricity generation and energy saving. The value of sustainability grew in importance.[10] This resulted in an increased search for sustainable ways of electricity generation and to save energy by using the heat efficiently with CHP installations (Blok, 1993). A number of stimulating measures were directed at sustainability and energy efficiency of the system, as will be further discussed in this section. Furthermore, in the 1980s liberalization started to become an important political paradigm. It was felt that the lack of competition in this electricity system withheld the energy companies to strive for continuous cost reductions and therewith increase economic performance of the system. This is further discussed below.

Regarding the formal institutions government intervention in the form of commissions and advisory boards had become more apparent in this period as the energy sector became regarded as an important sector for the economy.[11] With the Electricity Act 1989 the distribution companies could purchase electricity from any producer by a system of flexible contract prices and a dynamic spot price (Vlijm, 2002), whereas previously distribution companies were obliged to purchase electricity from the regional electricity companies. The objective was to stimulate the concentration of production companies and for distribution companies to better link up with the particular region (Noort, 1993a). The new Electricity Act, however, also permitted uncontrolled placement of small scale generation. This resulted in an unexpected and unbalanced growth of distributed generation. This is qualified as a misalignment (further discussed in section 7.2) to which the government responded in 1995 by a CHP moratorium. Other formal institutions in this period were a number of subsidy schemes that stimulated the implementation of sustainable electricity generation. Next to investment grants there was the 1979 agreement on favourable conditions for standby power contracts.[12]

With regard to the institutional arrangements, in 1970 eleven production companies signed the Collaboration Agreement,[13] mainly for the yearly national plan to determine the needed expansion in production capacity and the related internal accounting of capacity and electricity (Stuart, 2004). This plan covered 20 years with detailed plans for generation (location, fuels, capacity) and networks for the first ten years (Zantinge, 2004). The government considered it a deficiency that it had no legitimacy in the approval procedure of this Electricity Plan. This resulted in a covenant that came about in 1975, in which the minister had to approve the Electricity Plan. For the permissions of new plants and national transmission lines the Structure Scheme Electricity Supply[14] (SEV) was the leading institution. In the period 1973-1977 the Ministry of Economic Affairs proposed a five islands plan for economies of scale and production and distribution of electricity allocation with five new companies. There was, however, not sufficient support for this plan. In the subsequent period of government 1978-1981 the Commission for concentration of utility companies[15] (COCONUT) pleaded for economies of scale in the sector. In 1986 fifteen electricity companies organized their production into four separate companies (Vlijm, 2002) and by collaborating and participating in one large production company these four companies were involved in large scale generation of electricity. The relevant provincial and municipal governments held a participation in this large scale production company (Vlijm, 2002) so the control could be maintained as much as possible with the individual shareholders instead of with the new entity. The four big Dutch electricity producers were also the owner of the high voltage transmission network through their participation in the SEP (Bijkerk et al., 2003). The SEP was granted a central government concession per project on the basis of the 1989 Electricity Act. The central production would be coordinated and optimized by the SEP. The decentralized generation would be controlled by the regional electricity companies or private companies. In 1986 the New Collaboration Agreement (OvS) was signed by the participants and the SEP and came into effect in 1987. This agreement differed from the previous agreement in that it arranged the fuel use, cost accounting and allocation between SEP and its members as well as the reduction of the number of production companies (Vlijm, 2002).

Another relevant institution with regard to government and energy actors was the governmental National Environment Plan[16] (NMP) of 1989. This plan covered the protection of the environment and gave an impulse to the introduction of CHPs. Individual Environment Action Plans[17] (MAP) were worked out by distribution companies to comply with the NMP (Vlijm, 2002). As discussed in the previous sections, distribution companies freely installed small scale combined heat and power installations as permitted by the Electricity Act 1989 (Verbong and Geels, 2007). Government regulations stimulated distributed generation and new institutional arrangements such as standard contracts and joint ventures were constructed between electricity companies and industrial companies with regard to CHP installation in which the benefits and risks of the CHP project could be adequately arranged. As noted previously, this subsequently stimulated the deployment of decentralized generation and resulted in an overcapacity of small scale generation and potential problems with balancing of the network (see e.g. Steen et al., 2008). Stimulation of sustainable energy generation (often distributed generation) still continues to date with various subsidy schemes.[18]

Liberalization

In the 1980s liberalization started to become an important political paradigm and the idea took hold that it would be economically more efficient to liberalize the network industries (telecom, electricity, post, railways, etc.). Many countries started the liberalization of these network industries (see e.g. Newbery, 1997; Bergman et al., 1998) that were typically strictly government controlled. In the electricity sector, this paradigm was accompanied by a trend of professionalization and cost-efficiency. For example, the management of these companies was required to develop new skills with regard to marketing and coaching. To improve the cost efficiency of the sector efforts were made to finding an optimal scale for energy companies and consolidating current companies (Vlijm, 2002). In 1996 the third Energy Note[19] was issued with a clear message of liberalization of the energy market. Directive 96/92/EC on Common Rules for the Internal Electricity Market in the EU resulted in regulations to achieve a comparable level of opening-up the electricity market of each country. In the Netherlands this was followed with the Electricity Act 1998 which extended the market mechanism to the consumer side (Vlijm, 2002), particularly for the generation, trade and supply function. The transport function would be regulated. Subsequently, the management of the 21 regional distribution networks was placed in separate companies. Different types of electricity organizations evolved from this liberalization. The first type involves the production companies without a network or regional function (e.g. EON and Electrabel). The second type refers to the former regional distribution companies with a production and supply function. These companies have been legally unbundled from their production part to comply with the Electricity Act 1998 (e.g. Essent and NUON). As noted previously, the network function is organized in a separate legal entity under a holding company together with production and supply function (Künneke and Fens, 2007).[20] Third are the new supply companies (retail companies), the new entrants that buy electricity on the electricity market and subsequently sell it to the consumers. These companies typically do not own any production facility or network (e.g. Oxxio and Greenchoice). Furthermore, the SEP was abolished and as an institutional measure Tennet was established to take care of the essential functions of the system (further discussed in section 7.2.3).

Logic

The primary change in culture with regard to the electricity system is the change from the dominant economies of scale paradigm to a distributed generation paradigm. Next to practical reasons, a major reason is the attitude that became dominant in this period with regard to environmental issues impacting on DG deployment. As addressed previously (section 7.1.2), this change at the informal institutions level has been a driver impacting on other institutional layers. For example, we identified a number of regulations and subsidy schemes which stimulated the distributed generation. Furthermore, we noted some institutional arrangements, such as standard joint ventures and standard contractual arrangements which drove the distributed generation deployment. Next to the distributed generation paradigm, there was the economies of scale paradigm which drove the national government for a concentrated market of fewer but bigger energy companies. Institutional arrangements were made as a first step to mergers and acquisitions in the sector. The cultural aspect of the liberalization, i.e. the liberalization paradigm, that arose in the 1980s and 1990s triggered other parts of the institutional layers to be adapted as well in order to attain a certain logic. The liberalization paradigm goes along well with the Electricity Act of 1998. The non-regulated part of the system coincides with the liberalization paradigm as being an important cultural element in the electricity sector. As a consequence of this act the national government installed a regulator and thereby controls to a certain extent the regulated part of the electricity system. In sum, the distributed generation paradigm together with the liberalization paradigm as an informal institution has impacted on the other institutional layers.

7.2 Alignment in a hybrid system

In this section we address the alignment issues relevant to the modernization process of shifting the system to a hybrid system. We start with the alignment issues that are involved with the implementation of distributed generation. Then we discuss some key alignment issues that are involved with the implementation of international interconnectors. Lastly we elaborate on important general alignment issues that relate to the institutional unbundling and liberalization of the electricity sector.

7.2.1 Distributed generation and power quality

As addressed in section 7.1.2, problems with regard to DG became apparent in the 1980s and 1990s when existing institutions did not adequately coordinate the central and decentral production capacity. The institutions, such as the payback tariffs for CHPs (Brunekreeft, 1997) and the standard contracts and joint ventures with industry, caused the unbridled growth of CHPs and led to an overcapacity of large scale generation and potential problems with balancing the network. In 1994 decentral production covered 22% of the whole load (Vlijm, 2002). In coherence literature terms we note that the capacity management function was not safeguarded by the institutions in place which implied a potentially incoherent electricity system. Adjustments in the institutional framework were urgently needed (Verbong and Geels, 2007). In 1995 a moratorium as an institutional measure was applied to CHPs to be implemented by distribution companies. In conclusion, misalignment, i.e. existing institutions and the capacity management, was followed by institutional change, i.e. a CHP moratorium (Figure 29).[21]

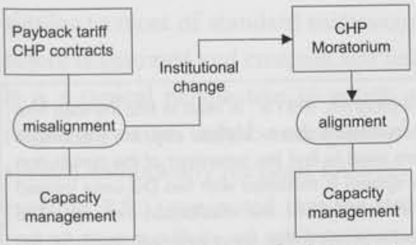

Figure 29 Misalignment drives institutional change

According to Mr Gerard Maas of Union for the Coordination of Transmission of Electricity (UCTE)[22], balancing problems in the system are a result of the fast growth of DG as the producers of distributed generation in most countries are not compelled to announce their production schemes for the next day to the TSO (EN, 2007e). Information about the production schedule of the CHPs is necessary to operate the technically integrated system. As a technical measure this could be solved by e.g. automatic centralized control over the independent CHPs or extra coupling networks to cope with any imbalance.[23] The institutional measure can be the mandatory daily announcement of the production scheme.[24] In conclusion, the misalignment, i.e. capacity management short term and current institutions, induced institutional change and modernization of the system (Figure 30).

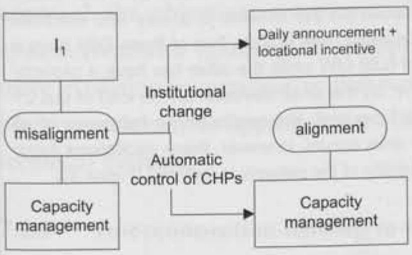

Figure 30 Distributed generation and power quality

Another prominent problem of a large scale DG penetration in the existing electricity system is the potential occurrence of frequency instability.[25] Cardell et al. (1998) focus on the primary dynamics, which occur during the first few seconds after a system disturbance. They state that the larger the number of generators, the more likely instability will occur. According to Jonker and Nazari (2007) another variable might be found in the location of the DG units in the electricity system. This implies that the institutional measure concerning the incentive to locate DG at a favourable place might prevent frequency instability (Figure 30).[26] This study is further elaborated in an illustration in section Box 1. This illustration is a typical approach of formalism in which 'the structure of reality is approximated by the logical structure of the calculus, or difference equations.' (Wilber and Harrison, 1978: 63). Statements in this study are determined from a logical deduction,

Box 1 Illustration of frequency stability

Jonker and Nazari (2007) executed a study largely based on Cardel et al. (1998) to determine the extent to whether location of a generator would play a role in the frequency stability of the electricity system. A mathematical model was used with a set of input, output and state variables related by first-order differential equations as a representation of a physical system, which is referred to as state space modelling (see e.g. Siljak, 1978; Jamshidi, 1996).

First, generator models were used as input for the individually modelled distributed generators based on Cardell et al. (1998) with three or four variables to represent the states of the generator. The types of generators are the steam turbine, the combustion turbine and the hydro turbine together with the specific values for the parameters in the generator models used in our system simulations.[1] The capacity of the generator is either 0.5 or 0.75 MW, which could supply energy to many consumers and would typically be installed and controlled by an electricity supplier.

The distribution network test system is a IEEE 30 bus test system (Figure 31), a radial distribution system consisting of links (lines) - and nodes (buses) (based on Cardell and Ilic, 2004; 1998; Haesen et al., 2006) and converted into a mathematical representation. Modelling the dynamic system enabled simulating the dynamic interactions of distributed generation facilities in response to system disturbances.

Subsequently the individual generator models were coupled via the distribution system and these equations were expanded to an extended state space and a full system model. The distribution system is represented by the set of load flow equations, the data of which is based on Grainger and Civanlar (1985) and Santoso and Tan (1990) and plugged into the load flow program. Different scenarios for DG penetration are used with varying number of generators, generator types, location and capacity.

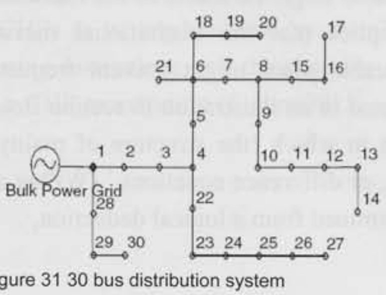

Figure 31 30 bus distribution system

A load flow program, IPSYS[1], is used to find the load flow and the equilibrium point. Matlab and an Eigenvalue analysis are used to find the behaviour of the distribution system. A system is modelled with two DG units located close to each other in the distribution network. The analysis demonstrated that the equilibrium point for the system cannot be found (no power flow solution), which indicates that the power cannot be transferred from DG locations to the other sections of the network. This means that the network is not stable due to the location of the DG units.

In case that the DG units are placed in the network in a way that electrical distance between them is reasonable high, the dynamic behaviour of the network improves significantly. It is, therefore, concluded that when these units are located close to each other, the coupling between units increases, due to the low electrical distance between them. Furthermore, it escalates the interaction of DG units and thus causes frequency instability.

As the importance of location of the DGs has been demonstrated a scenario is modelled with four steam turbines placed on the network in a way that electrical distance between units is high. Two of these DGs have a capacity of 0.50 MW while the other two have a capacity of 0.75 MW. By the small deviation on the load of bus 21 equal to 0.1 per unit, the oscillation on frequency of all these four units occurs. However, these oscillations damp and the stability of the network is restored (Figure 32).

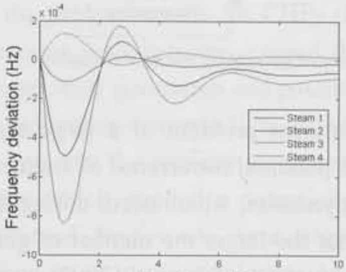

Figure 32 Dynamic behavior of four steam turbines

Whereas Cardell et al. (1998) highlighted the number of generators in the system as the most important variable to instability this study concluded that the stability of the system depends highly on the location of the generators and the electrical distance between the generators. We note, however, that as the study is part of ongoing research with a number of aspects to further investigate conclusions should be taken as tentative.

similar to most of standard microeconomics. In this reasoning the rational behavior of the actors is assumed and customs and habits are ignored (Wilber and Harrison, 1978).
It is a typical perspective in which a technical system can be designed. This perspective might, however, only be adequate if a number of conditions is met, such as a distribution system without any previous DGs (as in Figure 31). However, considering path dependence (section 2.5.1) we noted that the decisions that can be made are strongly influenced and constrained by the past which restrict the room to manoeuvre in the future. This aspect is neglected in the illustration, but of utmost importance in the actual long term performance of the system. Other aspects that are assumed in the above mentioned perspective are the sound coordination of the location of generation facilities, and the guarantee of no future interconnections of network, which could possibly decrease the electrical distance. Also, the institutions with regard to ownership and control of the distribution facilities are of utmost importance in the technical functioning of the system.
In reality the conditions as assumed in the illustration above might not hold. This brings about the complexity that is involved with the socio-technical system of distribution networks as yet another illustration that the design of such a system is rather difficult due to the complex interrelationships in the socio-technical system. This is an important insight for both engineers and policy makers who sometimes confine to a design approach of networks clinging on to either a technical or economic institutional perspective respectively. In their approach the objectives are presumably reached by simply changing a small part of the system therewith ignoring the complexity and the interrelations of the whole system. A more evolutionary perspective that would include the path dependency of the system would be more relevant to approach the complexity that accompanies the functioning of socio-technical systems.

7.2.2 Interconnection leading to misalignment

Whereas the international interconnected synchronous AC system implicate that the sub systems assist each other in case of a disturbance, it also implies that a major disturbance might propagate throughout the whole interconnected system and therewith endanger its stability. The electricity flows over the Dutch networks is very much dependent on the location and distribution of the production facilities abroad (Zantinge, 2004). For example, the windmill farms in the north of Germany can suddenly cause an enormous production of electricity. If this is accompanied by a large load in the south of Germany, where a lot of industry is, it travels via the Dutch electricity network, using much of its network capacity. According to Tennet in 2005 the Netherlands were twice at the verge of a blackout as a result of these unexpected currents (Elsevier, 2005). This case can be qualified as misalignment from the mismatch between the technical scope, i.e. the international interconnected system, and the national institutional system and coordination. A technical measure that was taken was the implementation of phase shifters at the border in Meede and Maasbracht. These phase shifters act as valves in the system therewith controlling the inflow of electrical energy from abroad and hence limiting the technical scope of the system. This is a clear technical solution with which to control the electrical energy and distribute it as desired over the network.[27] Although there was a request from the Dutch ministry to the German ministry to solve these electricity currents, the network operator Tennet acted beforehand to rule out any of these problems in the future. A way to expand the institutional scope and match it with the new technical scope would be to set up international rules and regulation for coordinating current flows and the placement/location of big generation facilities. Coordination could, furthermore, be executed by an international organization that would take care of these issues.[28] According to Mr Corné Meeuwis, the director of the Capacity Allocation Service Company for the Central West-European electricity market (CASC-CWE)[29] there is much to gain with such international tuning (EN, 2008a). In conclusion, modernization, i.e. the international synchronous interconnection, was followed by misalignment (i.e. international unforeseen flows) which was followed by modernization.[30] In the future this might be followed by institutional change (Figure 33).

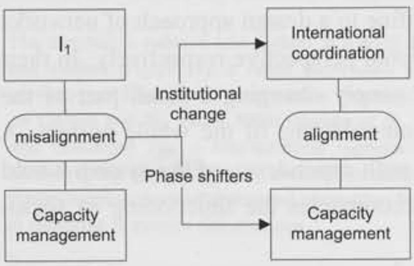

Figure 33 Misalignment resulting in institutional and technical change

Alignment problems such as the above example also occur nationally. In the case of not fully unbundled entities (e.g. merely legal unbundling) the production and transport entity of the same holding company can be more easily coordinated. However, with further unbundling this can become an additional challenge. For example, economically developing areas can create such a quick and large demand for transport capacity that request for connection cannot be always granted in time.[31] According to Mel Kroon, CEO of Tennet, the problem is that the plants are much faster constructed than the networks (EN, 2007b). For example, the lead time for a coal fired power plant is about four years and for a large network reinforcement it is about ten years.[32] This is an illustration of the misalignment of different elements in the electricity system. Another example is the Magnum power station of producer NUON to be built in the Eemshaven with a capacity of 1200 MW (see also EN, 2007a). Tennet argues that there is a 'mismatch between the increased production and the capacity of the network' (EN, 2007d). Especially in the north of the Netherlands and the Randstad (a conurbation in the Netherlands) this leads to problems. In recent years more and more of these bottlenecks have arisen in the transmission network. An urgent capacity problem is emerging as Tennet is meeting the limitations of the current 380 kV network (EN, 2008b), the reverse salient in LTS terms (section 2.4.1). The same capacity management issue holds for CHPs and distribution networks as for big plants and transmission networks. The network growth is lacking behind in the long term (Boersma, 2006).

An important other factor is the location and concentration of these new generation facilities. An example is the growing number of CHP installations in the 'Westland' in the Netherlands that want to deliver electricity to the grid. Nowadays these CHPs are not connected to the main grid as a consequence of capacity limits (Stromen, 2007; EN, 2007d). On the other hand, the distribution system operator (DSO) and the transmission system operator (TSO) are (institutionally) compelled to connect the CHP's on request and make further adaptations to the network. A technical measure is, therefore, the reinforcement of the network to increase the network's capacity. An institutional barrier to increase the network's capacity can be found in the permits and consultation rounds that accompany the implementation of new networks (EN, 2007b).[33] There are different institutional measures possible to solve this issue. First is the enhancement of the permission procedures, e.g. by making use of a National Coordination Regulation[34] which overrules major time-consuming hurdles in the permission procedure of network installations (Roggenkamp, 2008). The Ministry of Economic Affairs has made this regulation effective since March 2009. Another institutional measure refers to the transport restrictions that are given to the connectors until the transport bottlenecks are solved. Network operators indicate that solving the bottlenecks can take a period of two years (KEMA, 2006). Other institutional measures are to offer non-guaranteed transport capacity, to allocate scarce network capacity with a bid ladder[35] for not producing electricity or an auction of transport capacity (EN, 2008b). The option for a bid ladder has been implemented January 2009 in the Westland. Due to this congestion management the threat for a total stop on new connections and the stop of supply by CHPs is lifted. Such control systems will be called on to handle ever-more-complex problems under increasingly stringent and demanding conditions (Varming et al., 2002). We conclude that foreseen misalignment, i.e. capacity management and existing institutions, induces institutional and technical change (Figure 34).[36]

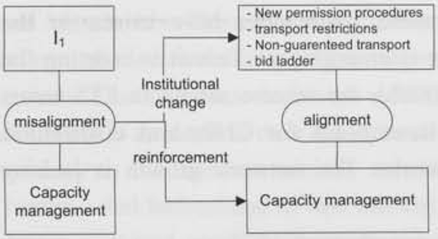

Figure 34 Generation and network implementation with different lead times

7.2.3 Critical functions safeguarded

As noted in section 7.1.2, as a result of liberalization SEP was abolished and Tennet was established to take care of the essential functions of the system. An example of such a function is the load balancing, which is coordinated through a balancing market in which traders can bid their price for selling energy and buying energy in order to balance the system. Tennet has a number of institutional coordination mechanisms in order to cope with balancing supply and demand in case that the actual values of supply and demand deviate from the predicted values.[37] Certain other essential functions were taken care of by the several codes that were prescribed in the Electricity Act. Another aspect is the reactive power which used to be managed with different power plants under the control of SEP. Nowadays Tennet has to arrange its own facilities for reactive power through contracts for system services as an institutional measure (Enslin et al., 2003) or with technical measures by installing more MVArs tension controllers and compensation for capacitive and inductive power via electromagnetic coils (usually copper wires), Tracom (coil system and compensation coils in a transformer).[38] Furthermore, Tennet has installed capacitor banks (a number of capacitors connected in series or in parallel) in the network. In this way Tennet can produce reactive power without dependence on production plants as the production sources are not to their direct disposal.

Another essential function Tennet is involved in is the capacity management long term. The Electricity Plan by the SEP and the Structure Scheme Electricity Supply used to be the institutional arrangement to align production with transport capacity. It was abolished with liberalization and for the network part substituted with a Quality and Capacity Document[39] (KCD). This document comprises among other things of norms with regard to building, maintenance and operation, objective for the reliability of the supply, risk analysis for the network, and the demand for transport capacity of the relevant part of the network for the next 10 years. This document has to be submitted to the regulator by the network operator bi-annually. Network operators argue that the KCD is an integral part of their business planning and the central document for attaining their goals. Together with the tariff regulation it is an impulse to operate the network more structurally and professionally. The Tariff Code[40] is part of the Netcode (discussed later in this section) and prescribes how the costs of the electricity network should be divided among the different buyers. In such a system the regulator determines the maximum tariff of the network services that the regulated company, i.e. the network operator, can charge. This maximum tariff is annually determined based on the Consumer Price Index lowered with an x-factor, the discount factor to stimulate efficient management based on the average of other network companies. The x-factor is the expected grade of improvement of productivity (DTe, 2002) as imposed by the regulator in the first regulation period (2000-2003). The second regulation period (2004-2006) the q-factor was introduced for regional network operators to take into account the quality of the network. Whether it actually safeguards the reliability is a question to be answered. Especially for the long term the reliability of the network might be at danger as a result of the ageing processes of its components (KEMA, 2006).[41] Network operators deal with this issue differently in the execution and depth of risk analyses and the fundament of the maintenance and replacement budgets.[42] Network operators indicate that the Electricity Law, especially the tariff regulation, is an impulse for sweating the assets and no incentive to pro actively replace assets. It is not clear to what extent the network deteriorates as a consequence of the financial pressure of tariff regulation (KEMA, 2006). According to KEMA (2006) the quality regulation is said to only be sufficient for adaptation of processes and procedures for reducing the downtime. So it does not result in extra investments in the network to prevent these interruptions (Figure 35).

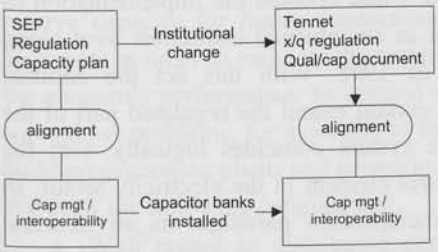

Figure 35 Abolishment of the SEP and interoperability and capacity management issues

Other essential functions that needed to be maintained were proscribed in the Netcode[43] and the System Code. [44] The System Code comprises of the instructions that are necessary to keep the system integrity. The Net Code comprises of the rules and regulation for the network companies with regard to investments in the network. It also describes the conditions for connections to the network and the execution of electricity transportation. The Measuring Code[45] is a code that prescribes the conditions with regard to the way that network operators and buyers should act with regard to the measurement of data relevant to electricity transport and exchange of measuring data. The Collaboration Regulation[46] aims at an optimal alignment of the network operators. In this way all individual network operators should be able to fulfil their tasks and duties. Every network operator is mandated to take into account the possible results of his actions to the execution of the legal tasks of other network operators. In addition, the network operators are obliged to inform each other adequately or collaborate if it contributes to attaining the goal of fulfilling their legal obligations. Last is the Information Code, which prescribes the conditions with regard to the way that network operators and buyers should act with regard to registration and exchange of information between the market parties. In conclusion, the changing institutions, i.e. the abolishment of the SEP, resulted in foreseen misalignment with regard to capacity management and interoperability which was followed by institutional changes.

7.3 Conclusions

This period is characterized by a shift to a system that combines distributed generation with large scale generation. In this period also liberalization played a large role. In the part on the socio-technical context we elaborated on this liberalization and the abolishment of the SEP as a coordinating body for a number of important essential functions of the electricity system. We, furthermore, showed how some essential functions are now safeguarded by Tennet or laid down in the Netcode (section 7.2.3).

The logic in the period is based on the informal institutions of distributed generation and liberalism. We argued that the paradigm of distributed generation was induced by the environmental concern. The laws and regulation directed at stimulated CHP (DG) were shortly adopted by the sector with regard to certain specific institutional arrangements – certain joint ventures and contractual arrangements – that boosted the implementation of distributed generation. The liberalization paradigm as an informal institution went along well with formalization in the Electricity Act of 1998. With this act the national government installed a regulator and controls to a certain extent the regulated part of the electricity system. The non-regulated part of the system coincides logically with the liberalization paradigm as being an important cultural element in the electricity sector. In sum, the distributed generation paradigm and liberalization paradigm as an informal institution has impacted on the other institutional layers which has resulted in the logic of the institutional system in this period.

Furthermore, we discussed some important alignment issues that are involved with the implementation of distributed generation. We found that there are many technical and institutional issues involved in the implementation of DG. DG implementation might have a large impact on some critical functions such as load balancing, voltage and frequency stability. Next to specific technical ways to cope with these issues such as better controls, we noted some institutional measures such as a mandatory announcement of the production scheme to improve balancing. Another suggested institutional measure was to have institutions in place that would safeguard the stability of the system by incentives for the optimal location of DG in the system.

Subsequently, we discussed some key alignment issues that are involved with the implementation of international interconnections. An important issue is the unwanted and sudden electricity currents from a neighbouring and interconnected country. This was illustrated by the case of the German windmills that jeopardized the Dutch electricity networks a number of times in 2005. From this illustration we learn that although this misalignment could have been solved by institutional measures such as rules with regard to the curtailing of the windmill generation, a technical measure in the form of installation of phase shifters was taken to cope with this issue. With regard to the institutional logic we argue that it were the relevant actors themselves, i.e. the network operators, who solved this problem instead of the national governments. This is remarkable as you would expect with an issue of this importance that it would be measures from the national government that would solve this problem.

We elaborated on important general alignment issues that relate to the institutional unbundling of the electricity sector. Next to specifics of real time operations we focused on the lack of central planning with regard to production facilities and transport capacity. We argued that new institutions are needed for the capacity management long term to be safeguarded. There is a misalignment that can be lessened by shortening the time to obtain the formal permission to build the transport facilities. If we want to remain a good match between the functions of the electricity supply chain institutional measures such as new permission procedures and transport restrictions are necessary in order to maintain the desired technical and economic performance. However, if we would only focus on the technical performance we might opt for more reinforcement of the network with a certain reserve capacity for future connections. This is a mere technical solution to safeguard alignment in order to maintain the technical performance, but with a trade off with regard to the economic performance. In general we argue that formal regulations can be helpful to solve these problems, for example, to facilitate the matching of the implementation time of building generation plants and networks.

We draw the following conclusions:

- With regard to distributed generation we observed that misalignment, existing institutions and the capacity management, induced institutional change in the form of a CHP moratorium.
- Changing institutions, i.e. the abolishment of the SEP, induced in foreseen misalignment with regard to capacity management long term and interoperability and was followed by institutional change of Tennet, KCD and regulation, and technical change of controls and capacitor banks.
- Modernization, i.e. international interconnection, drove the misalignment resulting in international unforeseen flows which drove the modernization of the system with phase shifters.
- Foreseen misalignment, capacity management and institutions unbundling the transport from the production capacity, is followed by institutional change (permission procedure, etc.) and technical change (reinforcements).

Notes on Chapter 7

[1] Interview with SUP01, held August 1, 2006; Interview with NET12, held August 21, 2006.

[2] For a thorough assessment of the technical challenges that accompany DG we refer to papers with regard to the technical and institutional issues regarding DG, such as Püttgen et al., 2003; Donkelaar et al., 2003; Donkelaar, 2004; Nielsen, 2002; Ropenus and Skytte, 2005; Ackermann, 2004.

[3] A further step would be to have these smart meters control electrical appliances automatically.

[4] In Dutch: 'Innovatie Ontwikkelingsprojecten - Elektromagnetische Vermogenstechniek'.

[5] Interview with NET16, held August 23, 2006.

[6] Similar problems have been discussed in section 6.2.2

[7] Interview with SUP07, held October 2, 2006.

[8] Paragraph based on Interview with SUP01, held August 1, 2006; Interview with NET12, held August 21, 2006; Interview with NET13, held August 22, 2006.

[9] most prominently *Limits to Growth* commissioned by the Club of Rome (Meadows et al., 1972)

[10] Although the functions are interlinked, we note that this relates more to the generation of electricity than to the transport of electricity.

[11] This had several reasons. First, a big amount of natural gas was discovered in the 1960s in which the central government got actively involved. Second, the report of the Club of Rome put the energy consumption on the agenda, and last, there was the oil crisis of 1973 (Vlijm, 2002).

[12] See Blok (1993) and Appendix B.

[13] In Dutch: 'Overeenkomst van Samenwerking'.

[14] In Dutch: 'Structuurschema ElektriciteitsVoorziening'.

[15] In Dutch: 'Commissie Concentratie Nutsbedrijven'.

[16] In Dutch: 'Nationaal Milieu Plan'.

[17] In Dutch: 'MilieuActiePlannen'.

[18] Regulations for electricity generation are the Energy Investment Deduction (EIA), a tax exemption for the adoption of innovative technical appliances that use less energy than appliances based on conventional technology. Small scale electricity generation such as combined heat and power appliances are typical appliances that are eligible for subsidy under this scheme. Another subsidy scheme is the CO_2 reduction plan. This government scheme subsidizes projects that have less CO_2 emissions than comparable standard projects. Another subsidy scheme is the Environment Quality Electricity Production Scheme (MEP). This scheme was a supply-oriented subsidy scheme that replaced previous demand-oriented tax exemptions (Verbong and Geels, 2007). It is a feed in tariff in which the subsidy is a fixed amount for every kWh that is produced and fed in to the electricity system. This subsidy scheme has in the recent past been a driver for the installation of wind mills and CHPs in horticulture. The Subsidy Scheme Sustainable Energy (SDE) is the successor of the MEP. It is an exploitation subsidy that finances the non feasible part of projects that involve renewable gas and electricity.

[19] In Dutch: 'Energienota'.

[20] Künneke and Fens (2007: 1922) distinguish between 'administrative unbundling: separate financial accounts for network exploitation and for sales/production, but shared operational activities under one company; management unbundling: in addition to administrative unbundling, staff are assigned to different business divisions/units that function independently from other business activities, but are still managed from a central holding; legal unbundling: network activities are organised in a separate legal entity, which might, however, function in a holding company together with production and sales activities; ownership unbundling: the network functions under different ownership from production and sales, thus no all-encompassing holding and no shared operational activities.'

[21] Partly based on Interview with NET11, held August 15, 2006.

[22] Since July 2009 on the European Network of Transmission System Operators for Electricity (ENTSO-E has taken over all operational tasks of the six existing TSO associations in Europe, including UCTE.

[23] Interview with NET13, held August 22, 2006.

[24] This is of course not feasible for intermittent generation facilities such as wind mills and photo-pholtaics generators which can only be forecasted.

[25] First, due to the difference in scale of the rotors of generators the inertias of the DG are typically smaller compared to the inertias of large central generators. Smaller inertias create stronger coupling between the system dynamics and the local frequency. Distributed generators have relatively smaller damping capacities and thus are less effective in rapidly damping oscillations. A second important attribute is the higher line resistance of the distributed network compared to the line resistance of the transmission network. This larger resistance of the lines in the network represents a larger dampening characteristic towards oscillations than the resistance of the transmission lines.

[26] We refer to the Appendix for the methodology, scenario's and results with regard to frequency instability.

[27] Interview with NET02, held July 24, 2006.

[28] According to Mel Kroon, the CEO of Tennet, network operators can and should align their investments better as control transformers in one country can have significant implications for a neighboring country (EN, 2007c).

[29] CASC-CWE is established in 2008. It is a service company that will act as a single auction office to implement and operate services for the yearly and monthly allocation of power transmission capacity on the common borders between the five countries based on standardized systems and rules.

[30] The alignment in this illustration depends on the perspective. In the Dutch network it relates to alignment with regard to this critical function. However, on the German network this might lead to misalgnment as the network might not be suitable to transport these large electrical currents.

[31] The opinions for the MV-network in the Netherlands are mixed. In a survey among 162 sector specialists the results are that 46% agrees that the present MV-network is not adequate for decentralised generation while 54% disagrees (Dutch-Power, 2006).

[32] Interview with NET02, held July 24, 2006.

[33] In similar cases the British have come up with the necessary permits rather easily (EN, 2007d).

[34] In Dutch: 'Rijkscoordinatieregeling'.

[35] In such a bid ladder companies would bid a price for not producing electricity. In case of congestion the coordinating body would collect and award the lowest bids until it reaches the amount of electricity production that the system can handle.

[36] Paragraph based on Interview with NET03, held July 27, 2006; Interview with NET07, held August 2, 2006 and Interview with NET12, held August 21, 2006.

[37] There is a Program Responsibility of the electricity suppliers that needs to inform Tennet about the exchange of electrical energy for the next day. This rule is directly enforced by the Electricity Act. Second is the bidding and dispatching of regulating reserve power and settlement of imbalances as laid down in the Grid Code and the System Code (Veen, 2007) for an elaborate discussion.

[38] Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006.

[39] In Dutch: 'Kwaliteits en CapaciteitsDocument'.

[40] In Dutch: 'Tarievencode'.

[41] Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[42] One network operator only considers the planned projects for the whole period, while other operators consider the next five years within a framework of long term prognoses (KEMA, 2006).

[43] In Dutch: 'Netcode'.

[44] In Dutch: 'Systeemcode'.

[45] In Dutch: 'Meetcode'.

[46] In Dutch: 'Samenwerkingsregeling'.

[illegible]

Part 3 Innovation System perspective

8 Methodology

In this chapter we address the research question and the research methodology with regard to the perspective of the innovation system. We, furthermore, discuss the method of identifying the important variables impacting on innovation of electricity network components and subsystems. Additionally, we distinguish two periods in our empirical research: the period prior to the liberalization and the period since the liberalization. We conclude this chapter with an elaboration on the structure of the empirical findings in Chapters 9 and 10.

8.1 Research question

In the perspective of innovation systems we are specifically interested in the institutional variables that impact on innovation. We study the influence of the institutions in the past and the present with special attention to the period before and after the liberalization assuming that such an institutional change can provide useful insights. The main research question with regard to modernization from the innovation system perspective is the following:

What are important variables in the modernization of electricity networks in the Netherlands from the innovation system perspective?

We first make an inventory of the relevant institutions in the past and present and secondly we explore to what extent the identified institutional variables impact on innovation. Again note that we are trying to understand the relationships in the modernization process and that we not aim to assess the variables in a logical deductive sense (as explained in section 1.5). This leads us to the following sub question: which were important institutional variables impacting on innovation prior to liberalization? With regard to the current situation we pose the sub question: which are important institutional variables impacting on innovation since liberalization? Subsequently, we will compare these two distinctive periods – the period prior to and the period since liberalization – with respect to the relation between institutions and innovation.

The focus in this innovation system perspective is on the network companies (or network operators) and the technology suppliers being the main actors in the process of innovation with regard to electricity networks. The network operator and the supplier can both perform innovative activities with regard to electricity network equipment. The supplier of network technology is typically the actor that supplies the network operator with the innovative technology. Prior to liberalization the network issues were typically taken care of by the integrated energy company. Since liberalization the network function has been regulated and these activities are placed in an individual legal entity. Accordingly we refer to the energy company as being the network operator prior to liberalization and to the network company as being the network operator since liberalization.

8.2 Research approach

We use the institutional layers as depicted in Figure 10 to structure the identified important institutional variables. We follow both a dynamic and static approach in this study. By conducting interviews we are able to capture the dynamic interactions between the institutional layers (the OIE approach as elaborated in section 2.3). We aim to understand the relationships between the institutional layers in order to pinpoint the origin of institutional change and to understand the 'logic' of the system (section 2.3.2). By a longitudinal approach we can identify changes in the institutions at different layers and identify possible differences in institutional change resulting in a disturbance of the logic between the layers. Additionally, it enables us to determine which layer is important for innovation under what circumstances, i.e. the conditions under which, certain layers become important.

In a survey we use a comparative static approach as in NIE (elaborated in section 2.3) and consequently do not consider the influence from one institutional layer to the other. We consider the institutional factors the exogenous variables impacting on innovation (see Figure 36) and aim to quantify these variables. Although such an approach is often used, its practical value in policy making can be questioned. Whereas it might result in a quantitative assessment of an array of variables, it might be hard to convert these quantified variables into policy recommendations as these variables might only be working in combination with other variables. These other variables can be either the other variables that were identified as important in their impact on innovation, but it can also be the contextual or facilitating variables that are external to the model. Despite these aspects we will execute the survey to get a view on the size and sign of the important variables in modernization, but we handle the quantitative results with care emphasizing the limitations of their practical use.

In the empirical research we aim to understand the behaviour of actors towards innovation in different institutional settings. As discussed in section 2.3.1 and 2.5.3 we identify actors at different levels: actors can be organizations as well as individuals who operate inside organizations. When we consider organizations as actors we are able to observe in the environment of the organizations the overall socio-economic changes. When we take individuals as the actors we are able to observe changes in organizational structures and the effects on individual actors with respect to their innovative behaviour. In other words, with the possibility to move in Figure 10 between the different layers we are able to identify institutions and institutional change at different levels and we are able to explore variables at different levels with different actors. An important aspect that we can come across is called in the literature the 'agent sensitivity of institutions' (Hodgson, 2006) indicating the degree to which institutions determine the behaviour of the agents (touched upon in section 2.3.1). When agents have no room to manoeuvre, thus the institutional structure almost fully determines the innovative behaviour of the agents, we speak about a low agent sensitivity of institutions. In other situations actors have much more influence on the innovation and institutions then only provide a broad framework. The same holds for technology: technology can be 'unruly' meaning that actors have large 'latitude of choice', or technology can be determining.

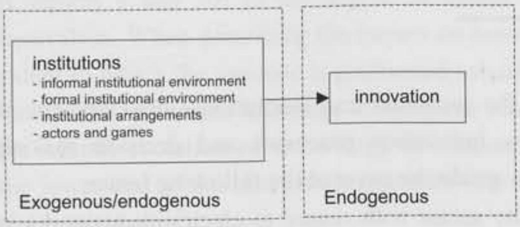

Figure 36 Institutions and innovation

8.3 Data collection

The empirical data were obtained by semi-structured interviews and a survey, to find both the intricate relationships of variables in the modernization process and to assess the sign and the size of these variables.

8.3.1 Interviews

A semi-structured interview is a method of research which makes use of a framework of themes to be explored.

> While a structured interview has a formalized, limited set of questions, a semi-structured interview is flexible, allowing new questions to be brought up during the interview as a result of what the interviewee says. [..] However, the specific topic or topics that the interviewer wants to explore during the interview should usually be thought about well in advance (especially during interviews for research projects). It is generally beneficial for interviewers to have an interview guide prepared, which is an informal "grouping of topics and questions that the interviewer can ask in different ways for different participants" [..] Interview guides help researchers to focus an interview on the topics at hand without constraining them to a particular format. This freedom can help interviewers to tailor their questions to the interview context/situation, and to the people they are interviewing (Lindlof and Taylor, 2002: 195).

The interviews were conducted from 2006 to 2008 with 33 Dutch electricity network experts (assets managers, R&D specialists, business developers, etc.) of whom 30 have a working experience in the electricity sector of more than ten years (Table 2). All experts have significant knowledge on innovation processes.[1]

Organization type	Persons	Organizations
Transmission network operator	7	1
Distribution network operator	14	5
R&D Consultancy	1	1
Supplier	11	7
Total	33	14

Table 2 Overview of interviewees/key experts

The semi structured interview related to the technical and institutional development of electricity networks and to the way how innovation processes and decision making processes took and take place. The interview guide the covered the following issues:

- typical innovations in the electricity sector with regard to electricity networks in the Netherlands;
- typical differences with regard to innovation before and after liberalization;
- important incentives (and hindrances) impacting on innovation prior to liberalization in culture (of the electricity sector), laws, regulation, organization, or otherwise;
- current (since liberalization) important incentives (and hindrances) impacting on innovation in culture (of the electricity sector), laws, regulation, organization, or otherwise.

The first issue allowed us to get an understanding of the concrete innovations in the Dutch electricity sector. The second issue allowed us to find different types of innovation, possibly as a function of the period in which it takes place.[2] The issues that followed cover the variables in the institutional layers and their impact on innovation prior to and since liberalization. These issues allowed for a deeper understanding of the complexity of the variables and their interrelations. Moreover, the responses on institutional variables were categorized along the institutional layers (Figure 10) which resulted in an overview of the important institutional variables that impact on innovation for network operators and equipment suppliers. In addition to the interviews, data was gathered through newspapers, sector reports, company records (e.g. annual reports) and databases from organizations as the International Energy Agency and EnergieNed to validate the findings from the interviews and therewith triangulate the empirical findings. The identified variables have been input for the survey.[3]

8.3.2 Survey

In the questionnaire for the survey the important variables from the interviews were categorized per period and per institutional layer. In the questionnaire we assessed to which degree the institutional variable impacted on innovation. The choices per variable on the scale are: 1. no innovation/no influence, 2. little degree of innovation, 3. some degree of innovation, 4. high degree of innovation, 5. very high degree of innovation. We are aware that such a measurement might be considered as measuring the degree of the same type of innovation, whereas the incremental and radical change is by definition of a different type. However, this approach complies with the concept of a sliding scale of innovation from slightly incremental (or no innovation) at one end of the spectrum and highly radical at the other end of the spectrum (explained in section 2.5.1). We refer in the empirical findings (Chapters 9 and 10) to the degree or extent to which a variable impacts on (radical) innovation. When describing the impact on innovation we refer to radical innovation, as the extent to which the variable is positioned towards the high end of radical innovation in the innovation spectrum. Although incremental innovation is also important it is regarded as the natural evolution of technology development and therewith analytically positioned at the lower end of the innovation spectrum (the scale and statistical analysis will be further elaborated below).

A test questionnaire was constructed and sent to three different persons: a senior asset manager for the consistency of the terminology with the jargon, a direct colleague for general consistency and the routing of the questionnaire, and a survey expert for the scientific consistency of the questions. Their comments were processed in the final questionnaire (see Appendices C for the questionnaire form). The survey was sent by email to potential respondents with a request to fill it in online. Respondents were found via the interviewees and through a list of key organizations related Dutch Power, the organization involved in knowledge exchange within the Dutch energy sector, and furthermore by asking respondents to connect us to eligible experts. We only selected respondents that had been working in the electricity sector at an energy company or were technology supplier both before and after 1998. We received 81 valid responses (17 non-responses). About 25% of the respondents were from network technology suppliers, 60% from regional distribution companies and about 15% from the national network companies.

Statistical analysis

The variables that are assessed with our questionnaire are of an ordinal scale.[4] The scale has much resemblance with a Likert scale[5] but deviates from a standard Likert scale in which the middle value is the neutral value. A Likert scale is somewhat different from typical ordinal scale examples such as the level of education and political parties[6] and hence Likert scales are often treated as being an interval scale. Whether individual Likert items should be considered as interval level data, or whether these should be considered merely as ordinal level data is the subject of a long term debate.[7] To be on the safe side, we handle our data as being of an ordinal scale and calculate as a main indicator for innovation the median, together with the 95% level confidence interval for the median. To gain a better understanding of the results we also include the mean as a parameter, which is typically done for interval data. We emphasize that we are careful in drawing conclusions from these mean values.

With regard to comparing prior and since liberalization, we included in our data set the respondents that worked at similar companies prior to and since liberalization. Since there are some essential objections to using ordinal data parametrically we do not apply the (parametric) paired sample t-test, but the Wilcoxon signed-rank test (Wilcoxon, 1945), which involves comparisons of differences between measurements.[8] One of the prime conditions to perform such a Wilcoxon test is that the differences in the pairs are distributed symmetrically. This is tested by a skewness-test in which the differences of the values per respondent are determined and subsequently used to calculate the skewness and the standard error of skewness. We use the standard threshold of symmetry which dictates that in the case that the skewness is more than two times the standard error of skewness, the null hypothesis that the differences are symmetric around 0 is rejected. However, the power of this skewness test, i.e. the chance to reject the null hypothesis, where it should factually be rejected, decreases when the sample size decreases. In other words, in such cases where we cannot reject the null hypothesis of symmetry the distribution might be symmetric (or non-significantly asymmetric) or the sample size might be too small to demonstrate the asymmetry. In cases of asymmetry one would confine to a more robust test: the sign test.[9] This test is, however, less powerful than the Wilcoxon signed rank test.

We choose to perform the Wilcoxon test as the standard test for the pairs that are not proven asymmetric by the skewness test. The sign test is performed for this group as an addition to have an extra check for the significance. If this test also finds a significant difference we can be sure of its significance. For the pairs that are proven to be asymmetric we only use the sign test.[10] We use a standard confidence interval of 95% (α=0.05) to assess the significance of the difference of the pairs. The p-value, represented by 'Asymp. Sign (two tailed)', should be less than the threshold of 0.05 in a non-directional test in case of a significant difference.[11]

8.4 Determination of periods in electricity development

In order to explore the influence of institutions on innovation we identified two periods: before and since the liberalization. The start of the liberalization of the electricity sector with the Electricity Act 1998 is a well accepted distinction in time when analyzing the electricity sector (see e.g. Winston, 1998; Zantinge, 2004; Bijkerk et al., 2003) and a comparison between the situation before and since the 1998 Electricity Law would reveal the major changes in the innovation activity in the sector. We stress that we can not attribute every development to liberalization as we acknowledge that other influences played a role as well.[12] Furthermore, any conclusions with regard to the impact of liberalization are tentative due to the relatively short time after liberalization. The start of liberalization in 1998 will only be used as a point in time solely to bring to light the differences in two different major periods.

We note that we focus primarily on the last few decades of the period prior to liberalization, but whenever appropriate to explain the origins of certain institution we will have a look further back in history.

8.5 Structure per chapter on specific period

We discuss the variables impacting on innovation prior to the liberalization in Chapter 9. The period since the liberalization is discussed in Chapter 10 together with the comparison between the two periods. We structure the chapters according to the layers of institutions as depicted in Figure 10. For each institutional layer we discuss the findings from the interviews that we conducted. We aim to highlight every variable individually, but it might in certain cases also be relevant to address a variable in relation to other variables in order to assess any interesting logic between the layers. In the informal institutional environment, we discuss the main cultural attribute of the sector and of the actors. It will provide us with an important sense of "the atmosphere" of the actors with regard to innovation (prior to and since liberalization). The informal institutions might act as an explanatory variable in the innovation behaviour of the actors. In the part on the formal institutional environment we discuss the laws and regulations relevant to innovation. Also subsidy schemes of electricity network components are addressed in this part.[13] In the part on institutional arrangements we discuss the modes of governance that are formed between the actors and that could drive innovation. In the part on actors and games we look more closely at the network company and the technology supplier. This layer refers to the internal structure of the organization that coordinates transactions as we discussed in section 2.3 and 2.5.2. After the findings from the interviews we discuss the variables from our survey. We use statistics to indicate the sign and impact of the variables.

Notes on Chapter 8

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[1] In order to maintain anonymity of the respondents we code the interviews and refer to the codes in the table in the appendix. For the encoded table we refer to Jonker (2008b).

[2] Although this question allowed for finding, for example, radical and increnmental innovation, questions were not always directed at finding these particular types of innovation.

[3] Due to some overlap in the period of conducting the interviews and the survey a few factors have been excluded from the survey or categorized under a different header. Furthermore, some factors are not relevant before or after liberalization and thus not thoroughly addressed in a certain period. The naming of the factors is at some points adapted to make it more in line with the current jargon in the electricity sector.

[4] In general measurements can be classified into four different types of scales: nominal, ordinal, interval and ratio (Stevens, 1946, Stevens, 1951), although other categories are also possible (see e.g. Velleman and Wilkinson, 1993, Chrisman, 1998). The nominal scale, or categorical scale, offers names or labels for certain characteristics. For example, rocks can be generally categorized with no particular order as igneous, sedimentary and metamorphic. The ordinal scale represents the order type of a certain order set. Ordinal categories can, for example, be the level of education and political parties on a left to right spectrum. Interval scales categorize quantitative attributes with similar distance or differences between adjacent points, but without a natural zero point. An example of an interval scale measurement the Celsius scale for measuring the temperature. The ratio scale has all the properties of an interval variable and it also has a natural zero point. An example is the Kelvin scale for measuring temperature. This is a non-arbitrary zero point as the particles that comprise matter at 0 Kelvin (absolute zero) have zero kinetic energy.

[5] e.g. strongly disagree, disagree, neither agree nor disagree, strongly agree.

[6] Assuming we can order parties ranging from very conservative to very progressive or from left wing to right wing.

[7] A number of scholars consider Likert scale data to possess strictly ordinal qualities, which implies that statistical measures would be restricted to frequency tables, medians and percentiles (Stevens, 1946). However, other scholars and other professionals practice other measures such as means and standard deviations from Likert scale data (e.g. von Eye, 2005). Also text books apply this approach on a large scale. Scholars that would oppose this approach for our research are concerned that the difference, or distance, between adjacent categories on the Likert scale are not equal. For example the distance between 'no innovation' and 'little innovation' would not be the same as between 'little innovation' and 'moderate innovation'. Although the interval difference might not be constant per se, it is in the same order of magnitude and hence such an item would fall between ordinal- and interval-level measurements. A recent study has addressed these topics and also demonstrated that data obtained from 5-point, 7-point and 10-point likert scales are approximately comparable in terms of mean score and various measures of variation and data shape (Dawes, 2008). Our Likert scale represents the interval level in a continuum with two extremes, i.e. 'no innovation' on the one extreme and 'very much innovation' on the other extreme. This continuum has been converted to discrete categories in which every respondent can position its view. However, the items in our questionnaires are accompanied by a visual analog scale, indicating equal spacing of response levels, which strengthens the argument for treating the data as interval level data.

[8] See e.g. also Douglas C. Montgomery, 1999.

[9] See e.g. Douglas C. Montgomery, 1999.

[10] This holds for the variable culture of pioneering with regard to the network companies and the variable of other collaborations with regard to network companies.

[11] In non-directional tests there is no expectation of the direction of the difference of the pairs prior to the quantitative test. In cases where we do expect a direction of difference between pairs, i.e. a directional test, the p-value is to be divided by two and this value should not exceed the threshold to qualify as being significantly different.

[12] An example is the deregulation of the labour market and the growing number of management layers in organizations (Kleinknecht et al., 2006).

[13] We omit subsidy schemes that are merely relevant to electricity generation as the electricity network is our object of research.

9 Prior to liberalization

In this chapter we elaborate on the most important institutional variables that affected innovation[1] prior to the liberalization of 1998 that were identified in the interviews. We, furthermore, discuss the results for the variables as determined with the survey that we conducted. We structure these variables along the institutional layers as discussed previously. First we discuss the informal institutional variables. Second we discuss the formal institutional variables. Third we discuss the variables with regard to institutional arrangements and fourth we discuss the variables with regard to the relevant actors in the modernization process. We end this chapter with conclusions.

9.1 Informal institutional variables impacting on innovation

9.1.1 Interview results

With regard to the informal institutional variables we found that in general the network companies and the suppliers of network technology used to have a clear social responsibility.[2] This is regarded as a general attribute rather than a variable that is specifically directed towards innovation. Social responsibility refers to the motivation of an organization like an energy company, to serve the public values, such as reliability and affordability. This social responsibility relates to the origin of the public utility companies and the fact that electricity is considered to be a universal service.[3] The following informal institutional variables that have affected innovation became apparent during the course of our research: culture of reliability, cost efficiency, conservatism, pioneering, prestige of innovation, a collaborative culture and the long term mindset.[4] These institutional variables are further explained in the following.

Network reliability

The culture of network reliability, or in general the reliability of the whole electricity system, was the main cultural attribute of the sector,[5] as households, the industry and the economy as a whole very much depend on electricity. The culture of network reliability was reinforced by the possibility of utilities to fairly easily discount costs related to innovations resulting in more reliable systems into the tariffs for consumers (further discussed in section 9.2). However, the culture of network reliability also made the actors in the electricity sector in some way reluctant to high risk innovations. First, due to the uncertainty of using an innovative technology there is a general reluctance to replace old equipment with innovative technology in case it is still performing according to the specifications.[6] The introduction of an innovation in the system might very well show shortcomings after a while. This is shown in the folowing example of the nekaldiet boots, the connecting element of electricity cables.[7] As it took less time to install these boots compared to previous technologies a large number of these boots were implemented in the MV network in the province of Groningen in the 1970s Although the boots passed the quality tests before being implemented, after a while major failures of the boots gradually started to occur.[8] This is, thus, an illustration of an innovation of which the failures started to manifest themselves after tests and after installation therewith decreasing the reliability of the system considerably. Despite the network reliability arguments to refrain from innovative activity, we identified a number of cases where the reliability culture was a driver to innovation. Examples are the shift from oil pressured cables to XLPE cables,[9] the shift from mechanical relays via electromagnetic relays to digital relays, the shift from pneumatic switches to electromagnetic switches[10] and going underground with cables, which made the system less vulnerable to falling trees.[11] These are all examples which would be characterized more as being radical than incremental innovations. In sum, we argue that the culture of network reliability has impacted on innovation both positively and negatively.

Cost efficiency

During and just after WWII materials for network technology and electricity network components were scarce. As there was quite some competition from other electricity companies to obtain equipment all technologies that would enter the market would get sold.[12] Cost efficiency in this period was less of a prominent issue as electricity companies were glad to purchase anything for the grid in order to reinforce or interconnect the electricity system (see also Chapter 6).[13] Innovation in this situation was dominated by a technology push (Unruh, 2000). According to an interviewee, this situation continued in the following decades.[14] In general, cost efficiency did not play a large role in this technology oriented sector.[15] Some interviewees suggested that the lack of focus on cost efficiency may have hampered innovative activity in some ways.[16] However, other interviewees argue that in certain cases the cost efficiency, or the culture of affordability of the electricity system, was a driver for innovation which resulted in changes in e.g. the HV transformer such as better materials, accurateness, and increase of the magnetic field and adaptation of the software to make controls more accurate.[17] In other words, the direction of this particular informal institutional variable impacting on innovation, i.e. positively and negatively, remains unresolved through the interviews. A quantitative approach might resolve this issue.

Conservatism

The previously addressed culture of reliability is related to the general variable of conservatism and risk averseness with regard to innovation. Any bad experience with innovation, e.g. the nekaldiet boots, contributes to the culture of conservatism. Many interviewees emphasized the conservativeness of the electricity sector,[18] arguing that conventional technology is 'proven technology', while new technology, although it might be better and cheaper, has a risk of failure. Network companies have a tendency to adopt conventional technology over innovative technology.[19] In other words, "the incentives are to invest in established dominant design technology over perceived risky alternatives." (Unruh, 2000: 825).[20] Furthermore, network operators do not get much extra credit for innovative technology, which explains their risk averse behaviour. If network operators would choose to adopt innovative technology, they would get the blame if that technology turned out to be failing, whereas they do not receive benefits if the innovation turns out to be beneficial to all actors in the system. In sum, conservatism is without doubt impacting on (radical) innovation negatively.

Pioneering

Although the culture of conservatism was very much present in the sector influencing innovation, also the culture of pioneering was very important in the electricity sector (Verbong and Vleuten, 2004). Most network industries were dominated by an engineering culture with an almost exclusive focus on technical aspects (Vlijm, 2002; Andriesse, 1993; Zantinge, 2004). The energy firms mainly comprised of engineers and many innovations were mainly executed out of and personal initiatives and 'hobby'.[21] Whether innovations were also economically feasible was not the first interest of the decision makers.[22] Every energy firm once in a while came up with an innovation.[23] There was little coordination in this, which explains the lack of standardization of the network components with consequences on the exchangeability of network components and interoperability of network sub systems.[24] The innovations from personal initiatives were not all particularly fundamental research efforts. These innovations could be better qualified as applied research to understand the working of particular physical concepts.[25] Innovation projects were permitted on the basis of authority of the person in charge, mostly an engineer, as there was no extensive formal selective mechanism related to economic viability of these innovative projects.[26] The pioneering culture has gradually evolved since the 1980s into more a formal professional attitude (see also section 9.4 on actors and games).

Prestige of innovation

The pioneering and engineering culture of network companies is related to the prestige of innovation. The reputation of the organization was closely related to its innovativeness, which was true for both the network companies and the technology supplying companies. The prestige of innovation for the companies in the electricity sector played a driving role in innovation processes. Despite the lack of market competition there was thus a stimulus for technology suppliers to be the first with a certain innovation.[27]

Collaborative culture

Due to the monopoly position of the electricity companies and particularly of the suppliers of network technology, competition in the sector was not very prominent (see section 9.3.1).[28] Hence, a culture of collaboration in the sector could easily be maintained.[29] Although there was prestige involved with a first innovation, the spun off technological knowledge was not valued as a competitive advantage. Hence, this new technological knowledge could be relatively freely distributed among the actors in the system. Innovation projects were sometimes executed in close collaboration with relatively small suppliers and network operators. Due to the informal relationships of the actors within the electricity sector, it was relatively simple to make these companies participate in innovation projects. Also the norm in the sector was to allow other parties to participate in innovation projects. It was custom to sent innovation project proposals to the main network operators and relevant equipment suppliers in order to give them the opportunity to be involved in these innovation projects.[30]

Long term orientation

A number of interviewees referred to the long term orientation of the energy companies and electricity network equipment suppliers with regard to innovation.[31] Also Vlijm (2002) argued that a large scale infrastructure as the electricity system required a long term orientation. This long term orientation was a driver to conduct long-term innovation projects with relatively risky outcomes in terms of financial feasibility. This stimulated the long term perspective and allowed for depreciation over a long term (Vlijm, 2002). Furthermore, the stable situation provided by the paradigm of economies of scale contributed to this mindset of a long term vision. This long term vision has in recent decades gradually changed to a more short term vision. This is further discussed in section 10.1.

9.1.2 Survey results

Table 3 presents the quantification of the informal variables that have affected innovation as assessed with the conducted survey. As mentioned previously (section 8.3) the survey results do not reveal the intricate relationships of the variables that are involved in innovation. It is, therefore, that we should take great care in drawing conclusion from the survey data.

As discussed in section 8.3.2 the results of the ordinal scale should be described with the median of the responses. The 95% level confidence interval for the median is shown between brackets. The often larger 95% level confidence interval for suppliers compared to the interval for the energy companies might be explained by the smaller sample size of the

former category respondents. The results in the table below show that there are some differences in median between the answers of the group of suppliers and the group of the energy companies. As the median is presented as an integer value some differences might be more emphasized while in fact the difference might be small.
The means of the dataset, however, indicate that there is a large similarity in the average value of the answers between the group of suppliers and the group of the energy companies.

Table 3 Statistics of informal institutions

	Suppliers			Energy companies		
	Median	Mean	n	Median	Mean	n
A98_reliability	4 [3,5]	4.0	19	4 [3,4]	3.5	54
A98_cost_eff	3.5* [3,4]	3.4	20	3 [3,4]	3.2	53
A98_conservatism	3 [2,3]	2.8	18	2 [2,3]	2.5	52
A98_pioneering	3 [2,4]	3.1	20	3 [3,4]	3.2	53
A98_prestige	4 [2,4]	3.4	30	3 [3]	3.1	52
A98_collaborative culture	3 [2,4]	3.1	19	4 [3,4]	3.5	54
A98_long_term	4 [3,4]	3.6	20	3.5 [3,4]	3.4	54

Between brackets is the 95% level confidence interval for the median.
* median is between 3 and 4.

The culture of network reliability and the long term mindset are two informal institutional variables prior to liberalization that have impacted innovation positively. The interviews suggested that the culture of reliability can be a driver and barrier to innovation. The survey, however, clearly suggests that the culture of reliability was an important driver to innovation. Furthermore, with regard to the variable of cost efficiency we observe a value between some degree and a high degree of innovation, which indicates that this variable is to a certain extent a driver to innovation. So that implies that although costs did not hamper the initiation of innovative activity, bringing costs down was a driver in starting these innovative activities. The survey shows that the median and mean for the variable of conservatism has the least positive impact on innovation, which was also expected from the interviews. These results comply with the results from the interviews.

9.2 Formal institutional variables impacting on innovation

9.2.1 Interview results

Two formal institutional variables that have affected innovation emerged from the interviews: regulation and tax exemptions.

Regulation

A national formal institutional variable impacting on innovation is the regulation imposed on electricity companies. Municipal companies, provincial companies and the national companies were regulated on the basis of rate of return. Depending on the type of energy company – municipal or provincial – permission to set the tariffs was needed by the municipality and province (or the ministry of Economic Affairs).[32] The extra costs for innovation of network technology could be fairly easily discounted in the price of the network equipment, as the energy company could fairly easily discount these higher prices and their own innovation efforts in the tariffs.[33] This held particularly for provincial companies. Municipal energy companies, however, were sometimes used as cash cows (see also Bijkerk et al., 2003), which ruled out the innovative projects, whereas in provincial companies there was more financial room for innovation.[34] Municipal companies were dependent on the permission for investments in network technology by the city council. Permissions of this kind took effort and time, so whenever proposals were submitted, these proposals were for big investments compared to the provincial proposals. Expansions took place stepwise in municipal companies, whereas any provincial permissions were more easily arranged and hence a more gradual expansion took place there.[35] In conclusion, we argue that as the national government did not intervene to a large extent in the direction of the innovations, which we qualify as a high degree of self regulation in the sector.[36] Most necessary activities were undertaken within the sector itself such as innovations with regard to the network. This self regulation has led to room on micro level for facilitation of innovation in the energy companies.

Tax exemptions

An important formal tax exemption with regard to innovation is the Law on Stimulation of Research and Development (WBSO).[37] This is a tax exemption for the working hours spent on research and development of physical products, processes and software. This tax exemption was initiated in 1994 (WBSO, 2004) at the eve of liberalization. The results of the subsidy scheme are more prominent since liberalization. Therefore, we discuss this subsidy scheme more extensively in the next chapter on the variables impacting on innovation since liberalization.

9.2.2 Survey results

Table 4 presents the quantification of the formal institutional variables impacting on innovation as a result of the survey. We see a difference in median between the suppliers and the energy companies with a value of 1 and 2 respectively (on a scale from 1 to 5). As the regulation with regard to electricity did only affect the energy companies, the value of 1 for the suppliers was expected. The value of the regulation before liberalization for the energy companies is also rather low implying that this institution did not have a positive effect on innovation. It could, furthermore, imply that the regulation was perceived as being absent, i.e. that there was a high degree of self regulation. This would confirm the findings from the interviews. We, furthermore, note that it has a relatively low value compared to the informal institutional variables, which implies that the informal institutional variables are a bigger driver to innovation than the formal institutional variable.

Table 4 Statistics of formal institutions[38]

	Suppliers			Energy companies		
	Median	Mean	n	Median	Mean	n
A98_regulation	1 [1]	1.3	20	2 [1,2]	1.9	53

Between brackets is the 95% level confidence interval for the median.

9.3 Institutional arrangement variables impacting on innovation

9.3.1 Interview results

A number of variables that have affected innovation with regard to institutional arrangements are identified with the interviews: property rights of the shares of the company, monopoly position and collaboration.[39]

Property rights/shareholder

In the period that we cover in this chapter the ownership of public utility companies was either in the hands of municipalities or provinces.[40] These companies were typically vertically integrated with the generation and supply function of electricity. Municipal companies were foremost integrated with regard to the distribution networks and retail.[41] Municipalities cashed large dividends from the municipal utilities (see also Bijkerk et al., 2003). Moreover, the provincial companies were substantially larger than the municipal companies and reserved more money for innovation.[42] This might (partly) explain the informal attribute of pioneering of current net companies that originated from provincial companies.[43]

Monopoly position

Suppliers of electricity network technology used to have monopoly positions in the market. There was little competition because orders from energy companies were placed fairly automatically and suppliers knew beforehand that their products would be sold.[44] Different standards and national ties hampered fierce international competition. Moreover, due to lack of transparency in tendering, the domestic parties in Dutch tenders were usually granted the assignments. Foreign parties could also submit bids, but these foreign bids were substantially higher (up to 50%) compared to domestic bids. This suggests a division of the market (and a monopoly) by electricity equipment suppliers.[45] One interviewee argued that the institutional variable of a monopoly position could also have hampered innovation as it formed a disincentive for technology enhancement.[46] In a seller's market without much competitive pressure the incentive to adapt and improve by means of innovation might be insufficient (Weijnen and Bouwmans, 2006). This could, however, been more than offset by the fact that the revenues of supplying companies were relatively high.[47] These revenues safeguarded the budget with which to conduct innovative activities. Prestige of the company as a previously mentioned informal institutional variable played a driving role in this quest for new technology.[48] The same held for utility companies. Also these companies were in a monopoly position (see also Künneke, 1999). Also for these companies the monopoly position implied a lack of market incentive to gain competitive advantage through innovation. In sum, we argue that the monopoly position alone cannot explain the innovations by the relevant actors. A combination of institutional variables, at different layers, such as the prestige of innovation is needed to explain the innovative activity. Next to combinations of variables that are needed to explain innovation, the example might also bring to mind that particular variables might drive different types of innovation. In line with Nooteboom (2000b) the institutional layers might act in a certain logic to stimulate either incremental or radical innovation (see section 2.5.2).

Collaboration

With respect to the collaboration variable we focused on the institutions that are involved in the interactions of actors with regard to innovation. From the interviews it was noted that energy companies used to execute a number of projects in close collaboration with other parties in the sector.[49] An interviewee noted the frequent collaboration of energy companies with network technology suppliers[50] and also included universities.[51] A number of innovative cooperative efforts were executed through the Collective Production Assignment[52] (COP) in which research was formalized.[53] The COP was accompanied by a substantial annual contribution by utility companies to the main research and development institution of the Netherlands: KEMA for electricity related research[54] and Gastec for gas related research (EOS, 2001). However, only limited resources were used for network related studies and most research funds were allocated to the production of energy.[55] Energy production was regarded as being the most fruitful research area. The research projects were executed with representatives of energy companies and EnergieNed in steering groups. The bigger energy companies contributed the most money, put the research topics on the agenda together with KEMA and benefited most from the outcome of the studies.[56] A number of interviewees state that a number of projects was rather questionable in feasibility.[57] Economic viability of these innovations did not seem a key priority. The COP research program was abolished in 1995/1996 at the eve of liberalization. Although only a small portion of the budget was dedicated to the network, it can be concluded that it did to some extent stimulate network innovation, although the economic feasibility of the innovation was questionable. This questions the implicit assumption of the benefits of innovation in general. It is often assumed that innovation is beneficial per se. However, the findings from the interviews suggest that the kind of innovation and its implications on a set of criteria, such as cost efficiency, safety, environmental friendliness, user friendliness, are other important aspects of innovation. In other words, innovation for innovation is perhaps not what should be aimed at. Innovation should be a means to an end, instead of an end in itself. This is further discussed in section 10.5 and 12.2.2.

9.3.2 Survey results

Table 5 presents the quantification of the variables addressed above as a result of the conducted survey. For a number of variables we observe a difference between the median of the results from the group of suppliers and from the group of energy companies. The COP is the one that apparently did not often include the suppliers as this variable is ranked very low by this suppliers group.

The shareholder (or property rights) variable seems to be a minor driver to innovation for both groups, albeit that the 95% confidence interval for the median value for the suppliers is rather large. This is due to the dispersion of the values for this variable, given that the sample size for the other variables of the suppliers is even smaller with a smaller confidence interval. If we look at the means of both we see that the mean of the suppliers is higher (2.4 versus 2.0). Although we should be careful in drawing conclusions from the values of the mean (also given the large confidence interval for the suppliers) it could indicate that the public ownership of the energy companies did not stimulate innovation that much as the private ownership of the technology suppliers did.

	Suppliers			Energy companies		
	Median	Mean	n	Median	Mean	n
A98_shareholder	2 [1,4]	2.4	20	2 [1,2]	2.0	53
A98_monopoly	2 [1,3]	2.2	19	3 [2,3]	2.7	52
A98_individual	4 [3,4]	3.6	17	3 [3,4]	3.2	52
A98_COP	1 [1,2]	1.5	18	3 [3,4]	3.2	51
A98_other_coll	2 [1,3]	2.3	18	3 [2,3]	2.8	49

Table 5 Statistics of variables of institutional arrangements
Between brackets is the 95% level confidence interval for the median.

The individual projects have the highest value for the suppliers suggesting being most favorable to innovation for this group. The individual innovation projects were a bigger driver to innovation for suppliers than innovation projects via the COP or other (informal) networks. For the energy companies this is not the case. For this group the individual projects and the projects via the COP are on the same level in being a driver impacting on innovation. Both the medians and the means are similar for these variables.

The variable of the monopoly position seems to be a bit in the middle of the other variables. This holds for both the suppliers and the energy companies, albeit that the 95% confidence interval for the median value of the suppliers is rather large. This can be explained both by the small sample size and the dispersion of the respondents' answers. The latter is likely given that other variables in the supplier category have smaller confidence intervals with a smaller sample size. Furtermore, there was also a mixed outcome in the interviews in which the monopoly variable can be a barrier to innovation, but is also associated as a driver or facilitator impacting on innovation.

9.4 Variables impacting on innovation with regard to actors and games[58]

9.4.1 Interview results

A number of variables that have affected innovation with regard to actors and games are identified with the interviews: small local actors, a dominating share of engineers, the availability of R&D/testing facilities, professionalization and formalization. These are explained in the following.

Small local actors
After WWII a number of national suppliers emerged, such as suppliers of cables and switches, suppliers of transformers and suppliers of converters as part of the electricity sector. Moreover, the energy companies and the suppliers increased their cooperative efforts with regard to innovation.[59] In this period the energy companies and their technology suppliers were rather small and local. Due to the size of these organizations it was fairly easy to engage in small-scale innovative projects.[60] Testing of new technologies was more easily approved of by the person in charge due to the informal links between employees in a small company.[61] When energy companies wanted to have a certain innovation, grass roots innovation projects were relatively easy initiated either by the energy company or by the technology supplier. This technology supplier subsequently put the innovative technology into production and supplied the produced technologies to the energy company.[62]

Dominating share of engineers
As stressed in section 9.1 in most companies in the electricity sector there was an engineering culture due to the dominant share of engineers in most companies. These engineers were, however, not per se the engineers with the most innovative capabilities that chose the relatively static, conservative and secure electricity sector.[63] However, having a major share of engineers in the company resulted in an engineering and pioneering culture where innovations were executed as a hobby, as personal initiatives (see also 9.1).[64] So next to the dependence on the kind of organization, any innovative capability and activity was also very dependent on a particular person.[65] In general, the CEO or director of the company used to be an engineer which was a driver in the innovative character of an organization.[66] Furthermore, it was found that it needs a strong and inspiring promoter,

preferably an engineer, in the company, be it a CEO or another person, for innovations with a longer time to market and thus with a longer payback period.[67] In the 1980s a gradual turnaround from public utility to professional company took place which involved making the organization leaner.[68] New personnel with mostly business and commercial skills were attracted (Vlijm, 2002). Many efficiency efforts were conducted in companies resulting in a substantial reduction in employment.[69] For the distribution network of ENECO the last 15 years 50% of the employees were let go (Heuvel, 2002). Within NUON around 30% of the employees were let go to comply with a new professional culture (Vlijm, 2002). As mentioned above, the gradual process of professionalization and formalization started already in the 1980s. It, however, became more manifest after liberalization which boosted the economic drivers of the electricity sector. The elaboration of this professionalization and formalization will, therefore, be in the next chapter.

Availability of R&D/testing facilities

Many technology suppliers and electricity companies, particularly provincial energy companies, used to have their in-house R&D and testing facilities (e.g. laboratories) in which they could conduct innovative research.[70] However, this did not apply for small companies, as a certain critical mass was needed to structurally engage in innovative activity and to establish these facilities.[71] The availability of R&D/testing facilities as an innovative capability impacts on innovation positively.

9.4.2 Survey results

Table 6 presents the quantification of the key variables with regard to actors and games. The results for the group of suppliers and energy companies are very similar in median and mean, except for the variable of small scale of the actor. Although the means are still pretty high, the median of the energy companies is rather low with a value of 2, compared to the value of 4 for the suppliers. This confirms our findings from the interviews that the small size of the company can have both advantages and disadvantages. Although the small size can omit a lot of bureaucratic barriers that hinder enthusiasm for innovation,[72] a critical mass is needed in the company to execute activities with regard to innovation.

The results show that an R&D department is considered to impact on innovation positively and substantially.[73] The same holds for the share of engineers in the company and an engineer as a CEO. These high values are expected. However, if we look at the suppliers' mean we see that the biggest factor for innovation in a supplier organization is a person who is an authority on innovation and is able to stimulate innovations. This is also the highest mean value for the group of energy companies. In general the variables in this category have a high score compared to the categories of formal institutional variables as presented in section 9.2 and variables with regard to institutional arrangements as presented in section 9.3. This suggests that the institutional layer related to culture and the actors provided the driving variables of innovation prior to liberalization. This suggests that the role of the central government was thus limited.

We emphasize that the variables with regard to actors and games are actually in the survey presented as general variables to innovation not specifically attributed to the situation prior to liberalization. As most of these variables are relevant prior to liberalization, we present the results of these variables in this chapter. However, this does not imply that every individual variable mentioned here is absent since liberalization, nor does it imply that it would have no impact in the situation since liberalization.

Table 6 Statistics of actors and games

	Suppliers			Energy companies		
	Median	Mean	n	Median	Mean	n
small_scale	4 [3,4]	3.6	18	3 [3]	3.1	49
share_eng	4 [3,5]	4.0	19	4 [4]	3.6	51
CEO_eng	4 [3,4]	3.5	19	4 [3,4]	3.5	50
authority	4 [4,5]	4.1	19	4 [4]	3.9	50
RD	4 [3,4]	3.7	19	4 [3,4]	3.6	50

Between brackets is the 95% level confidence interval for the median.

Table 7 presents the quantification of a number of important variables impacting on innovation with regard to the actors as a result of the conducted survey. We specify this per actor category. For some actors is it less easy to make a different characterization prior to and since liberalization as their transformation is rather gradual, compared to policies that can be changed instantaneously. Nevertheless, the table gives us an idea of the influence in the innovation per actor category. As can be seen in the table, the supplier seems to be the actor that has the most positive impact on innovation. The municipal energy company seems to be least in stimulating innovation, despite the fact that it is small in size which can enhance its impact,[74] also less than the provincial energy companies. This confirms the findings from the interviews which show that municipal companies are less inclined to innovate as a result of often being used as a cash cow (section 0). The mean values in the table, furthermore, suggest that the most innovative activity occurs at the suppliers of network technology.

Table 7 Innovative activity of different actors

	Suppliers			Energy companies		
	Median	Mean	n	Median	Mean	n
A98_muni	2 [2,3]	2.2	16	2 [2]	2.4	49
A98_prov	3 [2,3]	2.9	16	3 [3]	2.9	49
A98_supp	3 [3,4]	3.2	19	3 [3,4]	3.3	50

Between brackets is the 95% level confidence interval for the median.

9.4.3 Logic

The logic of the informal institutions in this period is one where a number of norms and values are in line with each other. The conservatism logically fits with the value of reliability. The pioneering and prestige of technology notion were also in line with each other. The collaborative culture worked well with the pioneering culture and the reliability aim. However, we also notice informal institutions that did not work in the same direction with regard to innovation, such as the pioneering/prestige of new technology and the conservatism. This suggests that the direction of innovation was thus based on a multidimensional complex system. Next to the logic within the layer of informal institutions there are logical links with other layers. One is the CEO as engineer, the large share of engineers, the R&D facility, the pioneering and the prestige for innovation. These variables fit very well together. Then there are other variables that work in line with these variables such as the small scale of the companies, which makes testing new technologies easy and the monopoly position of actors which leaves budget for innovative activities. In sum, we can characterize this period as being focussed on technology. Next to the culture of pioneering, there is some regulation but with very little influence on the innovative activity. There are some institutional arrangements (e.g. COP) that impact on innovation and the companies in the sector are characterized as engineering based companies.

The layers of informal institutions and actors were most important and aligned with regard to impacting on innovation. Overall the institutions were directed at long term, grass roots innovation that was predominantly informally undertaken within the engineering based companies.

9.5 Conclusions

In this section we draw conclusions based on the findings from the interviews and the survey with regard to the institutional variables that affected innovation prior to liberalization. It was found that some variables are evidently drivers impacting on innovation. However, for a number of variables the results are a mixture of drivers and barriers. It is not clear from the interviews what their net contribution to innovation is. An example is the variable of network reliability (section 9.1). It was discussed that there were network reliability arguments to keep using proven conventional technology. However, numerous examples show innovation efforts to improve the reliability of the electricity network. The network reliability thus acted as both a driver and a barrier in the innovation process. Another example is the culture of cost efficiency that can be both a driver and a barrier impacting on innovation. The quantitative assessments gave some indication of its net contribution. For example, with regard to network reliability, it can be concluded that this variable is more a driver than a barrier to innovation, concluded from the survey.

The net result can be determined quantitatively, but this does not disentangle the complexity of the particular variable. This implies that the interviews seem very useful to gain a more thorough analysis of the drivers to innovation than a mere listing of the variables with its net impact to innovation. Such a list does not reflect the complexity involved in modernization with its intricate relationships. In section 0 we have demonstrated that the monopoly position alone cannot fully explain the innovations by the relevant actors. Only combined with a prestige for innovation and necessary financial room for innovation it would drive innovation. Furthermore, the monopoly position of technology suppliers reduces the risk that network companies do not want to buy this new innovative technology. Another example of interrelationships is the obvious link between the pioneering culture and the dominance of engineers within an organization. These are, thus, institutional variables at different institutional layers impacting on innovation. In sum, a combination of institutional variables, possibly at different layers, have in interaction an influence on innovation and a further study of such interrelationships might be needed to get a better understanding of the drivers to innovation. The extensive description of the arguments of the variable in the positive or negative direction towards modernization based on the numerous interviews gives us a much better understanding of the variables and relationships in the modernization process than a quantitative assessment. For the variable culture of reliability it was found that it can be a driver and barrier to innovation, but more importantly, it was shown how these specific relations of a barrier and driver hold with regard to innovation and under what circumstances.

It was argued by a number of interviewees that the grass roots innovations, e.g. the bottom up initiatives by the engineers within the organization, did not per se lead to technically and economically viable systems. These uncoordinated bottom up initiatives resulted in a situation of different standards in the different networks. This lack of standardization hampers connection of networks (e.g. due to different clock numbers of the electricity system) and the exchangeability of components.[75] Furthermore, there has been a trend of expanding functions of a component as the innovation was driven by engineers.[76] Technologies became more advanced, bigger and more complex. There was little tendency to make it simpler, as innovation was driven by engineers. However, next to the uncoordinated bottom up initiatives we discussed the coordinated innovation efforts such as the COP, of which the economic feasibility was at times questionable. This suggests that both the bottom up and the more top down innovation initiatives prior to liberalization were often not economically feasible. This is confirmed by the findings in the interviews that suggested that the financial means and the economic feasibility were not a big issue with regard to network technology. A question that arises here is whether such bottom up innovation should be strived for at all. As was indicated during the interviews, every innovation is exotic, so standardization and simplicity within the electricity system is important. This means that every deviation from the standard, i.e. innovation, should have a clear added value to the systems as a whole.[77] We can argue, however, that although there have been a number of innovations in the Dutch electricity sector this has not resulted in a unreliable system as the Dutch system is one of the most reliable networks of Europe (CEER, 2008).

From the interviews and particularly from the values of the survey we can see that the variables related to the informal institutions and to the actors and games were most dominant in determining the innovative activity of the electricity sector. These categories are in line with each other. This suggests that it was the culture with the actors instead of formal rules and arrangements that determined the innovation. We should, however, note that these layers are interwoven in the innovation system. In other words, although particular layers may seem most important in driving innovation, it does not imply that the variables in the other layers can be omitted. The results of the important layers impacting on innovation, furthermore, suggest and confirm that the sector was largely self-regulated and the intervention from the national government did not substantially enhance the innovative activity of the sector. In the next chapter we discuss whether these informal institutional variables to innovation still hold.

Notes on Chapter 9

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[1] As stressed in section 8.3.2, in the empirical chapters we describe the degree or extent to which a variable impacts on (radical) innovation. When describing the impact on innovation we refer to radical innovation. Although incremental innovation is also important it is regarded as the natural evolution of technology development (the base line scenario) and therewith analytically positioned at the lower end of the innovation spectrum.

[2] Interview with NET11, held August 15, 2006.

[3] This cultural attribute also relates to attaining a good public profile (Interview with NET01, held April 10, 2006.).

[4] Another variable that was not prominent in the interviews and therefore not included in the subsequent survey is the norms and values with regard to safety. This variable was very prominent in the sector, but not regarded as a n important variable impacting on innovation. Another driver was the sustainability. An example is the shift to sub stations without SF6 gas. It is hard to assess its value at this point, but the fact that it was not prominent during our interviews suggests that it is not very important with regard to innovation.

[5] Interview with NET02, held July 24, 2006; Interview with CON01, held August 11, 2006; Interview with NET11, held August 15, 2006.

[6] Interview with NET02, held July 24, 2006.

[7] In Dutch: 'Nekaldietmoffen'.

[8] Interview with NET03, held July 27, 2006.

[9] Interview with NET08, held August 9, 2006

[10] Interview with NET03, held July 27, 2006; Interview with NET04, held July 27, 2006.

[11] Interview with NET11, held August 15, 2006.

[12] Interview with NET02, held July 24, 2006; Interview with NET04, held July 27, 2006.

[13] Interview with NET02, held July 24, 2006; Interview with SUP04, held August 18, 2006; Interview with NET13, held August 22, 2006.

[14] Interview with NET02, held July 24, 2006.

[15] Interview with NET02, held July 24, 2006.

[16] Interview with NET02, held July 24, 2006.

[17] Interview with NET08, held August 9, 2006

[18] E.g. Interview with NET02, held July 24, 2006; Interview with NET03, held July 27, 2006; Interview with NET11, held August 15, 2006.

[19] Interview with NET02, held July 24, 2006.

[20] This has also been discussed under network reliability.

[21] Interview with NET02, held July 24, 2006; Interview with NET03, held July 27, 2006; Interview with SUP01, held August 1, 2006; Interview with NET08, held August 9, 2006, Interview with NET10, held August 10, 2006; Interview with NET11, held August 15, 2006; Interview with NET15, held August 22, 2006.

[22] Interview with NET08, held August 9, 2006, Interview with NET10, held August 10, 2006.

[23] Interview with NET02, held July 24, 2006.

[24] Interview with NET02, held July 24, 2006.

[25] Interview with NET11, held August 15, 2006.

[26] Interview with NET09, held August 10, 2006.

[27] Interview with NET10, held August 10, 2006; Interview with SUP05, held September 11, 2006; Interview with NET02, held July 24, 2006; Interview with NET13, held August 22, 2006.

[28] In the section on formal institutions the monopoly situation of suppliers and utilities is addressed.

[29] Interview with NET09, held August 10, 2006.

[30] Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[31] Interview with NET02, held July 24, 2006; Interview with NET13, held August 22, 2006; Interview with SUP05, held September 11, 2006.

[32] Interview with NET11, held August 15, 2006.

[33] Interview with NET10, held August 10, 2006.

[34] Interview with NET03, held July 27, 2006; Interview with NET10, held August 10, 2006.

[35] Interview with NET03, held July 27, 2006.

[36] As the energy companies were not all private actors, the term does not comply to the stricter definition by Porter and Ronit (2006: 43) who define self regulation as 'an arrangement, involving formal or informal procedures, rules and norms, that is widely recognized as having the purpose of constraining the conduct of a set of private actors, where the procedures, rules and norms are shaped to a significant degree by some or all of these actors.'

[37] In Dutch: 'Wet Bevordering Speur- en Ontwikkelingswerk'.

[38] The results of the tax exemption of the WBSO scheme are more prominent since liberalization and hence presented in the next chapter on the variables impacting on innovation since liberalization.

[39] Although vertical integration is a usual institutional arrangements als relevant to the electricity sector, this concept was not identified in this form as a variable impacting on innovation such as the other variables.

[40] We have seen in part 2 of this study that around 1900 also many private electricity companies existed.

[41] The national transmission network was owned by the SEP, which had the four major production companies as its shareholders.

[42] Interview with NET03, held July 27, 2006; Interview with NET12, held August 21, 2006.

[43] Interview with NET10, held August 10, 2006.

[44] Interview with SUP05, held September 11, 2006.

[45] Interview with SUP02, held August 2, 2006; Interview with NET02, held July 24, 2006.

[46] Interview with NET02, held July 24, 2006.

[47] Interview with NET02, held July 24, 2006; Interview with NET10, held August 10, 2006.

[48] Interview with SUP05, held September 11, 2006.

[49] Also competitors were included as the companies did not consider each other as competitors.

[50] Interview with NET03, held July 27, 2006.

[51] Interview with SUP04, held August 18, 2006.

[52] In Dutch: 'Collectieve Opdracht Productie'.

[53] Interview with NET09, held August 10, 2006; Interview with NET11, held August 15, 2006; Interview with NET02, held July 24, 2006.

[54] Interview with CON01, held August 11, 2006.

[55] Interview with NET01, held April 10, 2006; Interview with NET02, held July 24, 2006. and (EOS, 2001)

[56] Interview with NET02, held July 24, 2006; Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[57] Interview with NET10, held August 10, 2006;Interview with NET12, held August 21, 2006.

[58] Some of these variables are relevant for the period since liberalization as well. However, as these variables are more relevant prior to liberalization we discuss them in this chapter.

[59] Interview with NET02, held July 24, 2006.

[60] Interview with NET03, held July 27, 2006; Interview with CON01, held August 11, 2006.

[61] Interview with NET10, held August 10, 2006. A number of respondents from the survey (35, 45) note due to the size of municipal companies innovations could be fairly easily implemented.

[62] Interview with NET02, held July 24, 2006; Interview with NET03, held July 27, 2006.

[63] Interview with NET02, held July 24, 2006; Interview with SUP01, held August 1, 2006.

[64] Interview with NET02, held July 24, 2006.

[65] Survey data (respondent 2).

[66] Survey data (respondent 49).

[67] Interview with NET01, held April 10, 2006; Interview with NET02, held July 24, 2006; Interview with SUP01, held August 1, 2006; Interview with NET09, held August 10, 2006; Interview with NET10, held August 10, 2006; Interview with NET12, held August 21, 2006.

[68] For a more extensive overview we refer to the actor description in the Appendix.

[69] Interview with NET11, held August 15, 2006.

[70] Interview with NET03, held July 27, 2006.

[71] Interview with NET16, held August 23, 2006; Interview with SUP05, held September 11, 2006; Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[72] Survey data (respondent 35).

[73] The relationship could possibly also be vice versa in causality. This is not measured do to the scope of the research.

[74] Survey data (respondent 35, 61).

[75] Exchange of a transformer in Winterswijk and North Holland is for example not possible (Interview with NET02, held July 24, 2006.).

[76] Interview with SUP01, held August 1, 2006; Interview with NET17, held August 23, 2006.

[77] Interview with NET01, held April 10, 2006.

Interview with [illegible], held August 11, 2006.

Interview with [illegible], held April 10, 2006; Interview with [illegible], held May 24, 2006; and [illegible]

Interview with [illegible], held July 24, 2006; Interview with [illegible], held February 28, 2006; Interview with [illegible], held February 28, 2006.

Interview with [illegible], held August 10, 2006; Interview with [illegible], held August 9, 2006.

[illegible]

Interview with [illegible], held July 28, 2006.

Interview with [illegible], held July 27, 2006; Interview with [illegible], held August 11, 2006.

Interview with [illegible], held August 10, 2006. A number of respondents from the survey [illegible]

Interview with [illegible], held May 24, 2006; Interview with [illegible], held July 27, 2006.

Interview with [illegible], held July 28, 2006; Interview with [illegible], held August 1, 2006.

Interview with [illegible], held May 26, 2006.

Survey data (respondent [illegible]).

Survey data (respondent [illegible]).

Interview with [illegible], held April 10, 2006; Interview with [illegible], held July 24, 2006; Interview with [illegible], held August 9, 2006; Interview with [illegible], held August 10, 2006; [illegible] Interview with [illegible], held August 21, 2006.

For a more extensive overview we refer to [illegible]

Interview with [illegible], held August 15, 2006.

Interview with [illegible], held May 26, 2006.

Interview with [illegible], held August 27, 2006; Interview with [illegible], held September 11, 2006; Interview with [illegible] [illegible], 2006.

Survey data (respondent [illegible]).

[illegible]

Survey data (respondent [illegible]).

[illegible] Interview with [illegible], held July 24, 2006.

Interview with [illegible], held August 1, 2006; Interview with [illegible], held August 15, 2006.

Interview with [illegible], held April 10, 2006.

10 Since liberalization and comparison

In this chapter we address the institutional variables to innovation since the liberalization of the electricity sector in 1998. We discuss the informal institutions, the formal environment, the institutional arrangements and the actors and games impacting on innovation.[1] We, furthermore, compare the institutional variables before and after the liberalization. At he end of the chapter we draw conclusions.

10.1 Informal institutional variables impacting on innovation

10.1.1 Interview resuls

In the previous chapter it was found that the social responsibility of energy companies was a prominent cultural attribute with which to serve the public values (section 9.1). With liberalization this social responsibility has been imposed on the utility firms with explicit rules and regulation (e.g. in the Netcode[2]). New formal rules were introduced which probably have had an impact on the behaviour of the actors and on the development of the informal institutions. Another aspect of social responsibility is to attain a good public profile with regard to reliability, affordability, the environment and health issues which is also important towards municipalities and government bodies who decide on permits for implementation of the electricity network.[3] Other cultural attributes relevant for this period as identified in the interviews are conservatism, prestige of innovation, collaborative culture, short term orientation and the competitive mindset.

Network reliability

In Chapter 9 we elaborated on the network reliability as an important norm in the electricity system. At present households, the industry and the economy as a whole are still very much dependent on electricity from the grid and the culture of network reliability is still relevant at present. The Netherlands have currently one of the most reliable electricity systems in Europe (see e.g. Haffner, 2004). Like with this network reliability variable prior to liberalization, the current network reliability variable can impact on innovation both positively and negatively (see also section 9.1), something we aim to shed more light on by the quantification of this variable through our survey.

Cost efficiency

As mentioned previously, in this technology-oriented sector cost efficiency did not play an important role, although there was a general idea to safeguard the affordability of the system.[4] According to a number of interviewees, the culture of cost efficiency has become more prominent due to liberalization.[5] Furthermore, technology suppliers encounter a more dynamic and competitive market and therewith need to work on the margins of the products. Some interviewees argue that this current focus by companies on cost efficiency has increased,[6] which, has significantly reduced room for innovation,[7] which another interviewee stated that the cost efficiency is a driver for innovation.[8] What we did observe is that cost efficiency is a constant focus of companies, but that innovative activities should be economically feasible, something that is more prominent now than prior to liberalization. In sum, it is not clear from the interviews what the net benefit to innovation is for this institutional variable of cost efficiency. This is something which should be assessed quantitatively. However, it was suggested that the cost efficiency has a positive influence on incremental innovation, while it has a less positive influence on radical innovation.

Conservatism

The culture of conservatism in the sector as described for the situation prior to liberalization is currently still present.[9] This, of course, has a clear relation with the variable of network reliability as network reliability is typically reached by proven technology. Also emotion and routines still play a huge role as barrier to adoption of new technology.[10] An example is for instance the present reluctance to adopt DC cables instead of the more conventional AC cables for the national high voltage network. Engineers of Tennet have always used AC technology, so implementing technology with DC[11] does not comply with current engineering routines.[12] An example of a barrier with regard to the conservatism relates to the safety measures in Gas Insulated Substations. These substations are fully closed and have a good track record of performance. These are constructed with a double rail and a safety unit that detects the failure and the specific rail and disconnects the right part while the other part will remain connected. This safety unit makes it very complicated and therewith unreliable while the chance of failures is very small. Although it is statistically underpinned that it is better to omit this safety unit there is a lot of resistance to it as it gives a secure feeling to have the extra safety unit.[13] This variable is impacting on innovation negatively, the extent of which will be assessed through the survey.

Prestige of innovation

In the previous chapter we discussed the prestige of innovation as being an important informal institutional variable impacting on innovation. Nowadays, the prestige of innovation is still a cultural factor that plays a role,[14] especially since innovation is regarded as the way to improve economic benefits. Many interviewees noted, however, that nowadays less financial means are dedicated to long-term innovation projects.[15] Nabuurs, the CEO of KEMA, argues that energy companies are not so keen to innovate as

> they do not have to be the first with something new. Customers will be there anyhow, as there is no real competition. Companies are willing, but their existence is simply not dependent on innovation. Any activities that companies undertake in that field are pretty much without full dedication (Biesboer, 2009: 25).

This proposition contradicts with the findings from the interviews in which we found that it was a matter of prestige for companies to be the first with a certain innovation. Furthermore, some recent positive developments and new interest with regard to innovation can be observed. In order to expose their innovation efforts Alliander (previously Continuon), the former network company of NUON, issues an innovation and sustainability annual report. We, furthermore, note that in recent years more network companies attempt to promote innovation. It has been more formalized in specialized positions with innovation managers and specialized innovation departments, for example within Enexis (previously Essent Netwerk). Furthermore, we know of similar studies within one major network company to assess the innovative capacity of that company in order to improve it.

Collaborative culture

The culture of collaboration was an important informal institutional variable prior to liberalization in the electricity sector. This variable is still present nowadays although some interviewees point out that the sharing of information on technology has become less common after the liberalization of the sector.[16] The norm on asking other parties to participate in innovation projects is returning now, but some argue that there was a dip just after liberalization, as companies had to find a way of dealing with the new situation.[17] Moreover, cooperation is still present to an extent as the utility companies are still too small to do certain operations on their own and they are dependent on each other in certain cases. For example, as certain failures in the grid are infrequent, the experience with certain issues is limited, so utilities are still very dependent on each other and hence have to collaborate in these cases with knowledge sharing.[18] When, for instance, a transformer breaks, utilities cooperate to solve it and to understand the failure. In the past this also happened as a social responsibility to safeguard the network.[19] Communication can easily be established as there are still many rather informal relationships among engineers.[20] With regard to the collaboration between suppliers and network companies it is, furthermore, found that contractual agreements among network technology suppliers and energy companies are more detailed than before.[21] This will be further discussed under the header of the institutional arrangements.

Short term orientation

In the previous chapter we discussed the long term mindset of the actors in the electricity sector prior to liberalization. This mindset has gradually changed to more short term both for suppliers of network technology as for network companies with regard to profit and innovation. Suppliers have a shorter time horizon and hence use a shorter time to market, i.e. the time to develop a product until it appears on the market.[22] For an innovative project to be granted permission within the organisation, the short time to market is essential as the risk is just too high to engage in long-term innovative activities. This has resulted in a clear trend to short-term innovations,[23] which implies a shift from radical to incremental innovations.[24] This is illustrated by the garnitures, e.g. the cable connectors (boot) or the wire termination, of a company supplying electricity cables. These garnitures were the result of past R&D efforts lasting 4-5 years. Such an undertaking would not be possible in today's organization as innovative products should have a significant shorter time to market than before.[25] According to the 1993 annual report of ABB, a leading firm in network technology, 'special effort is being made to shorten the R&D life cycle and reduce the time to market for new products (ABB, 1994: 30). Although a strong correlation between more radical innovation and a long term orientation is most plausible, we stress that the opposite – i.e radical innovation in combination with short term orientation – could also be possible, albeit less likely. However, radical innovations that we encountered were a result of the long term orientation with regard to innovation (e.g. XLPE cables, pneumatic switches). More innovation occurs in secondary technology instead of the primary technology.[26] ICT has been a clear impulse for the innovation of electricity networks (Künneke, 2003). For example, sensors are implemented in the grid to monitor the temperature and to diagnose the degradation of materials of critical network components.[27]

Competitive mindset

After liberalization the monopoly structure changed into a more competitive one, both for the suppliers of equipment as for the (vertically integrated) energy companies.[28] At present, suppliers mainly compete on costs, which hampers product innovation.[29]

10.1.2 Survey results

In Table 8 we present the quantification of a number of important informal institutional variables to innovation as a result of the conducted survey. The left hand side of the table presents the values of the median, its confidence interval and the mean for the two actor groups, the suppliers and network companies, since liberalization. The right hand side of the table presents the comparison of these values for both actor groups with the values of these variables prior to liberalization. As discussed in section 8.3.2 this part of the table is combined with the relevant parts of the paired Wilcoxon signed rank test unless stated otherwise.

We see that the medians and means for the two actor groups (suppliers and energy companies) do not differ much. There are slight differences, such as the prestige for innovation, which seems to be a bigger driver for suppliers than for network companies. Furthermore, the culture of competition is the same for both groups if we only consider both medians. However, the means of both variables seem to suggest that the competitive culture drove innovation more for the suppliers than for the network companies.

Table 8 Statistics of informal institutions

	Variables since liberalization						Comparison with prior to liberalization			
	Suppliers			Network companies			Suppliers		Network companies	
	Median	Mean	n	Median	Mean	n	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig.(2-tailed)
P98_reliability	4 [3,4]	3.8	21	4 [3,4]	3.6	56	-.548[a]	0.584	-.185[b]	0.853
P98_cost_eff	4 [3,5]	4.0	21	4 [3,4]	3.7	56	-2.437[b]	0.015	-2.831[b]	0.005
P98_conservatism	2 [2,3]	2.2	20	2 [2]	2.4	54	-1.512[a]	0.131	-.293[a]	0.769
P98_prestige	4 [3,4]	3.6	21	3 [3,4]	3.3	56	-.741[b]	0.458	-1.667[b]	0.096
P98_collaboration	3 [3,4]	3.1	20	3 [2,3]	2.8	56	-.741[b]	0.854	-2.905[a]	0.004
P98_pioneering	2 [2,4]	2.6	21	2 [2,3]	2.6	55	-1.329[a]	0.184	-3.213[a 2]	0.001[2]
P98_short_term[1]	3 [2,3]	2.6	21	3 [2,3]	2.8	55	-2.336[a]	0.019	-3.363[a]	0.001
P98_competition	3 [3,4]	3.2	21	3 [2,3]	2.7	54	na	na	na	na

Between brackets is the 95% level confidence interval for the media; a. Based on positive ranks; b. Based on negative ranks.; 1. With A98_long term; 2. Sign Test.

From the interviews we learned that although reliability can be a variable to take a minimum of risks it can also be an impulse to improve the network with innovative and more reliable components and sub systems. The table shows that the median for the variable network reliability is relatively high from which we conclude that it seems more a driver than a barrier to innovation. We, furthermore, compare the value of this variable before and since 1998. The difference in mean value compared to the mean value prior to liberalization is different and in opposite direction for the two actor groups and insignificant as is demonstrated with a Wilcoxon test. This suggests that this variable is a steady cultural attribute in its relation to innovation as no significant change could be determined. Hence, we conclude that liberalization did not result in a significant change of the variable of reliability with regard to innovation. We note, however, that any conclusions with regard to the impact of liberalization are tentative due to the relatively short time after liberalization.

The cost efficiency seems to be a very important informal institutional variable having an impact on innovation as its medians are high for both actor groups, but also the mean is particularly high. The high value sheds some light on the mixed results from the interviews which suggest that cost efficiency reduces and stimulates innovation activity. The

Wilcoxon test shows a significant increase in the median for this variable for both actor groups.[30] This is a confirmation of the findings from the interviews that after liberalization the variable of cost efficiency plays an increased role with regard to innovation.

Another variable that came up multiple times in the interviews was the conservatism of the electricity sector. We observe a relatively low value for this variable for both actor groups which suggests that this was more a barrier than a driver to innovation. From the survey we see that the higher value of the mean of the variable before liberalization compared to the mean value of the variable since liberalization suggests that conservatism stimulates innovation less than it did before. In the interviews we did not find a direction of change before and since liberalization and hence our null hypothesis is on a difference between the two variables, i.e. non-directional (discussed in section 8.3.2). The Wilcoxon test result for the suppliers and for the network companies points out that the difference of the means is not significant. In other words, there is no significant difference in the variable of conservatism prior to and since liberalization with regard to its influence on innovative activity.

With regard to the prestige of innovation we observe that this value is relatively high, suggesting a driver to innovation. We mentioned above already that this variable seems to be a bigger driver for suppliers than for network companies, although the means of both groups for this variable do not differ that much. The Wilcoxon test demonstrates that the difference between the means prior to and since liberalization is not significant for either of the two actor groups.

Another variable is the culture of collaboration. Interviews suggested a lesser positive influence of the culture of collaboration since liberalization. If we compare the means of the variables prior to and since liberalization for the network companies we observe a substantial difference of the value prior to and since liberalization the significance of which is demonstrated by the Wilcoxon test.[31] The quantitative assessment, therewith, confirms the findings from the interviews.

As previously discussed, the pioneering culture has gradually evolved since the 1980s into a more formal company culture. In order to compare this variable to the variable prior to liberalization we included it in our survey. For the network companies and suppliers we see that its median is not very high and that it is lower than the value prior to liberalization. For the network companies, the Wilcoxon-test points out that this difference in medians is significant which confirms our findings from the interviews. These interviews suggested that pioneering was a true driver of innovation but one that should particularly be attributed to the period prior to liberalization.

The focus on the long term prior to liberalization and the short term since liberalization is a difference that was found in the interviews. The value of the short term variable from the survey is lower than the value for the long term variable (section 9.1.2, p. 119). This suggests that long term orientation impacts on radical innovation more than a short term orientation does, something which we hinted at previously. For both the group of suppliers

and the network companies the shift from a long term to a short term vision is significant as is depicted in Table 8.[32]
The last variable is the culture of competition. This variable was only included in the survey for the factors since 1998 as it became relevant since the liberalization. The findings from the interviews were mixed. Furthermore, from the result of the quantitative assessment of a median of 3 does not resolve the issue whether this variable is a barrier or driver to innovation.[33] It might be under certain circumstances and conditions that a postive or negative impact on innovation prevails.

10.2 Formal institutional variables impacting on innovation

10.2.1 Interview results

Through the interviews we identified a number of formal institutional variables that have affected innovation: tendering regulation, tariff regulation, tax exemptions and environmental regulation.

Tendering regulation
EU tendering is prescribed in the Utilities Directive 93/38/EEC of 1993[34] which coordinates the procurement procedures of entities operating in the water, energy, transport and telecommunications sectors.[35] The objective of this directive is to contribute to a competitive European market. We found mixed results from the EU tendering directive. According to some interviewees the contact between the technology supplier and the network company has become more formal.[36] To make further generalizations on the impact of this tendering directive we make a distinction between distribution and transmission system companies. For certain (small) DSOs EU tendering is less of a regular activity than for a TSO[37] and there seems to be less room for innovation in tendering for distribution network technologies.[38] This relates to a difference in assets for distribution networks and transmission networks and whether the price of the assignment meets a certain threshold above which EU tendering is required. In other words, it depends also on the type of project at hand. For example, in certain standard projects the cables and lines are just ordered off the shelf[39] and technology suppliers are confronted in the tender instructions with detailed technical specifications by the network company. Hence, some argue that the procedure for tendering of distribution network companies is rather similar to the situation prior to this directive.[40] Moreover, when a certain technology has proven itself (and innovation is not a real issue) the technology suppliers would only tender on costs. This might result in innovation in the production process to reduce costs – process innovation – instead of product innovation.[41] However, while some network companies are very strict in prescribing technical specifications other network companies use functional specifications for a tender (e.g. the required electricity transport capacity) and therewith leaving more room for innovation. In innovative projects it is also dependent on the

technological capabilities of the network company whether it is able to prescribe detailed technical specifications and therewith this network operator would do much of the engineering themselves.[42] More complex projects possibly require additional creative technological know-how from the technology supplier.[43]

For transmission system companies the project budgets are typically higher compared to projects by DSOs and often the project involves complex technical challenges. As the tendering procedure allows for a consultation round there is plenty of room to be innovative in these projects.[44] Especially with large projects, there is always a modus in the procedure to include innovation.[45] The project in such a tendering procedure is pretty much turnkey and the technical specifications need to be further explored in the tendering process. This relates to the trend to more functional specifications instead of technical specifications in their terms of reference for public tendering by the TSO, which gives room for innovation as the details of the technology are yet to be determined.[46] This trend, which makes comparison harder for granting projects,[47] might also be explained by the fact that most network companies used to have technical or scientific staff (see section 9.4). This staff was able to prescribe the technical specifications. Now that a large number of these engineers has mostly gone, innovations come more from the technology supplier (Vlijm, 2002).[48] This results in a big role for the technology supplier in the more complex projects (e.g. the NorNed project).

Regulation

In the previous chapter we elaborated on the regulation imposed on the energy companies prior to liberalization. With liberalization in the Netherlands price cap regulation was introduced for electricity network companies (e.g. Hattori et al., 2005). The rules and regulation for the network companies with regard to investments in the network are laid down in the Netcode. In the first regulation period (2000-2003) an x-factor was introduced, an efficiency factor as an incentive to cost efficiency that limited the discounting of network costs into the tariff. As cost efficiency due to the x-factor has been the prime criterion for granting projects by the net companies, the suppliers have been very much focussed on keeping costs low and innovating more on the production process of conventional technology than on the creation of new products.[49] Managers of technology suppliers in dynamic and competitive markets compete on the margins of exiting products to survive. We observed a mixed result from the interviews. According to some interviewees the focus on cost efficiency by the imposed x-factor has had a negative impact on innovation.[50] It was, argued that the regulation implicated a tendency to go from radical to incremental innovations.[51] This goes hand in hand with the current short term mindset of the actors in the electricity sector. The focus was more on short-term profit than possible long-term profits by creating new products. Interviewee argue that it has somewhat been a barrier to investments in infrastructure components in general.[52] It was argued that on a national local scale regulation could indeed have hampered innovation. Additionally, the lack of investments by energy companies could have been the final blow for small local equipment suppliers.[53] However, he also argued that liberalization in general did not have a negative influence on innovation and innovation budget. Creating markets has been a driver for more R&D, at least for equipment for high voltage (HV) components. The x-factor of the Dutch regulation has been a driver for adopting secondary infrastructure technology with regard to asset management to postpone larger investments in primary infrastructure components (see also section 2.1).[54] There is a tendency for network companies to extend the use of, or 'sweat', current assets.[55] Pier Nabuurs, the CEO of KEMA, observed that 'regulation is directed to cost reduction. Only the costs that are incurred in increasing reliability or capacity are allowed in the tariff. So this does not apply to the costs for innovation.' (Biesboer, 2009: 25).[56] That is why currently network operators show a decrease of innovation budget.[57]

In the second regulation period (2004-2006) a q-factor was introduced that took into account the quality of the network. This resulted in a driver for adoption of quality measuring and quality improving technology,[58] although according to some interviewees it did not act as an extra stimulus for innovation.[59] Either this q-regulation had no effect at all to these interviewees or it led to investment in proven technology instead of innovative and therewith risky technology. Others argue that the q-factor has been a driver for quality and innovation.[60]

Furthermore, it has been argued that an unstable regulatory environment since the 1990s has been a barrier to innovative activity. The regulatory risk is just too high to engage in long-term innovative activities. An example is the subsidy scheme for windmills (MEP) that unexpectedly was abolished in 2006. Such unexpected measures and the lack of a stable regulatory environment also with regard to generation facilities hinder technology suppliers to engage in innovations in network technologies with regard to windmills.[61] In sum, the regulation shows some mixed outcomes with regard to innovation. We can, however, conclude that this variable has a more positive influence on incremental innovation than on radical innovation.

Tax exemptions/subsidy schemes[62]

Formal tax exemptions that stimulate innovative activity existed prior to liberalization and still exist at present. First, there is the WBSO tax exemption initiated in 1994 at the eve of liberalization. It provides a tax exemption of a certain percent for the hours spent on research and development of physical products, processes and software. The private share in the subsidy scheme, which refers to the part of the costs of the loan that is not exempted under this tax regulation, has more than doubled compared to the numbers before liberalization in the category transmission, distribution and accumulation of electricity (see Figure 37). This indicates that there is a clear change in private spending in R&D since liberalization. Furthermore, it has grown fast from 1.3 million euros in 2000 to 10 million euros in 2005. Public funding in R&D was higher before liberalization than after liberalization as is indicated by Figure 37. It started of with low figures for the years 1990 and 1991. Since then we observe a rise with a peak in 1996 of about EUR 6.3 mln. After 1996 the number decline with the year 2000 as low point (EUR 0.4 mln). Since then the figures grow in the years 2001-2003. Due to the lack of data from 2004 onward we can, however, not draw solid conclusions based on these data.

We can see a turning point after liberalization with regard to expenditures on R&D. This is validated by the statements of CE, a Dutch research consultancy group, in their report on the effects of liberalization (Klooster et al., 2005) that argues that there is an increase on the expenditure for marketing at the expense of the budget for R&D. However, we also observe that from 2001 on the private share of WBSO projects has been rising to higher levels than before the liberalization. A possible reason for this is that with the ending of the COP (see section 9.3) network companies started to look for other ways of funding their innovation efforts

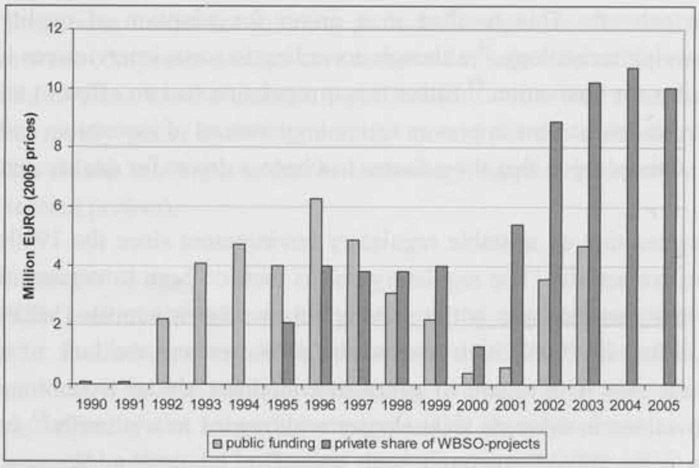

Figure 37 R&D budget of Electricity transmission and distribution in the Netherlands
Source: SenterNovem, 2006, personal correspondence with SenterNovem and International Energy Agency statistics on energy R&D; Public funding figures not available for 2004-2005, private share under WBSO figures not available for 1990-1994).

Other programs are the Innovative Development Projects (IOP).[63] This subsidy scheme stimulated projects related to Electro Magnetic Power Electronics (EMVT)[64]. These programs were initiated after liberalization to substitute the founding through the Collective Production Assignment (COP)[65], which we will address in the section on institutional arrangements.

Environmental regulation[66]

Environmental regulation induced by the growing public opposition against certain aspects of the electricity system, such as the visual pollution and magnetism of electricity conductors, has induced innovative solutions. The general public has become aware of its rights, an aspect that is, however, not directly attributable to liberalization. There are government restrictions on electromagnetic fields, visual pollution and other environmental issues to oppose the instalment of new network components.[67] For example, the requirements for installing conductors at sea are very strict as electromagnetic fields from the cable is supposed to influence compasses and internal orientation systems of fish and other animals. For the 580 kilometre long cable from the Netherlands to Norway, the NorNed cable, this resulted in innovations to go from a single to a double-cable structure HVDC, something that had not been applied before.[68] Moreover, environmental regulation resulted in HVDC Light, a newly developed conductor based on DC with lesser magnetism.[69] It has a capacity of 1100 MW and can economically compete with conventional AC technology from covering a distance of 30 kilometres onwards. This DC technology has a reduced magnetic field corridor of about 1-4 meters.[70] Another example is the Wintrack, an improved electricity pole with a lesser electromagnetic field that, hence, is presumed to be given easier right of way.[71] With regard to the installation of the cables different developments were observed. A distribution network operator until recently deployed its cables in one flat surface, but currently lays them deployed in a triangle to reduce the cables' magnetic field. This, however, also reduces the capacity of the cables due to increased heat generation. In order to maintain the capacity thicker cables are used.[72] Last, regulation on environmental noise was an incentive for technology suppliers to develop transformers with a reduced noise level.[73]

In conclusion, a number of regulations with regard to visual pollution, magnetism and noise are considered as formal institutional variables influencing innovative activity of electricity network components and sub systems.

10.2.2 Survey results[74]

Table 9 presents the quantification of formal variables to innovation as a result of the conducted survey. First we look at any differences between the suppliers group and the group of network companies. The regulation with regard to electricity is not directed at suppliers, which explains the low value. Possibly it deviates from the 1 value as they indicated the indirect effects of the regulation on their innovative behaviour. In the table we observe that the variable x-tariff is also not a very high figure for the network company, but also not very low. This complies with the findings from the interviews that this variable can act as a driver to short term innovations. This also complies with the findings from the interviews, although a number of respondents note the barrier of the current regulation to innovation. We, furthermore, observe that the xq-tariff variable has the same median but a higher mean value than the x-tariff variable with a larger difference for the suppliers than for the network companies. We do emphasize that the 95% confidence interval for the median value for both the suppliers and the network companies is rather large, which indicates the weakness of the median value. This might be explained by the small sample size, but given that the same sample size can produce a smaller confidence interval (e.g. for variable P98_x_tariff), it probably suggests that there is little consensus regarding the impact of xq-regulation on innovation. The variables x-tariff and xq-tariff compared to the regulation prior to liberalization show a difference in the medians. The significance of both of these differences is demonstrated through the Wilcoxon-test.[75] This suggests that the regulation before 1998 was worse in stimulating innovation than the regulation since liberalization. This outcome does not comply with the interviews as some interviewees suggested that current regulation may hamper innovation. An explanation can be found in the fact that many respondents rated the variable regulation prior to innovation with a value 'no influence' (as network regulation was not as prominent as it is nowadays) while they rated the variable since regulation with at least some minor influence to innovation. Furthermore, it is possible that the current regulation is more a driver to a specific type of innovation: incremental/short term innovation. This should then be confirmed in further research.

Table 9 Statistics of formal institutions

	Variables since liberalization						Comparison with prior to liberalization			
	Suppliers			Network companies			Suppliers		Network companies	
	Median	Mean	n	Median	Mean	n	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
P98_x_tariff	2 [1,2]	1.9	15	3 [2,3]	2.9	52	-2.111[a]	.035	-4.095[a]	.000
P98_xq_tariff	2 [1,4]	2.4	15	3 [2,4]	3.0	50	-1.911[a]	.056	-4.373[a]	.000
P98_tender	2 [1,3]	2.3	19	2 [2,3]	2.4	46	na	na	na	na
WBSO	3 [1,5]	2.8	14	2 [2,3]	2.3	20	na	na	na	na
IOP	3 [1,4]	2.6	15	3 [2,3]	2.7	34	na	na	na	na
EMVT	1 [1,2]	1.5	12	3 [2,3]	2.6	35	na	na	na	na

Between brackets is the 95% level confidence interval for the median; a. Based on negative ranks.

Tendering rules as imposed by the EU is rated relatively low by both suppliers and network companies. This confirms our findings from the interviews that indicated that the tendering rules were a barrier to innovation of electricity network components and sub systems.

Although higher than the tendering rules, the values for the subsidy schemes like the WBSO, IOP and EMVT are not rated very high. Furthermore, the 95% confidence interval for the median value for the suppliers is rather large, which indicates the weakness of this median value. This might be explained by the small sample size, but it might also suggest that there is little consensus among suppliers regarding the impact of WBSO and IOP on innovation. The EMVT scheme apparently was stimulating more innovation in network companies than in supplying companies. These results indicate that these subsidy programs are not considered strong drivers to innovation. Additional data gathering is needed to explain the relatively low value of these subsidy schemes. An explanation could be that the budget for these subsidy schemes is low compared to the other innovative activities by the sector actors for which none of the discussed subsidy schemes is used. According to a respondent the current subsidy applications are not weighed on their practical use, but on their fit with the original tender specifications.[76] It was also opted in the survey that these national subsidy schemes are often not used by international companies that do not have their R&D centre in the Netherlands.[77]

10.3 Institutional arrangement variables impacting on innovation

10.3.1 Interview results

Two variables with regard to institutional arrangements to innovation are identified with the interviews, which we discuss in the following: property rights and collaboration.

Property rights/shareholders

In Chapter 9 we discussed the property rights prior to liberalization. Especially the property rights of the energy companies in public hands proved to be a specific institutional variable impacting on innovation. Since liberalization the supply division of the integrated energy companies is acting in a liberalized market environment. Although the entities are legally seperated, the liberalization has had its impact on the network parts of the organization that are consolidated under the holding company.[78] Furthermore, there has been more focus on shareholder value than before[79], which stimulates the short term perspective that is more prominent nowadays. For certain shareholders the aim of the energy company is not to innovate, but to cash dividends.[80] Delays in cashing dividends for the sake of innovation are for shareholders often unwanted.[81]

Collaboration[82]

Prior to liberalization the COP was the main formal collaboration institution in the electricity sector (discussed in section 9.3).[83] After the Electricity Act 1998, the COP was replaced by subsidy programs in order to stimulate cooperation. The PREGO[84] program was a financial impulse by the government after liberalization to stimulate research on electricity networks as a response to the concerns for the security of supply after liberalization. This program lasted from 2002 to 2005 and comprised of a number of studies on network technology.[85] Other programs were subsidy schemes such as the IOP and the Energy Research Subsidies (EOS).[86] At the end of 2004 the cooperative net operators established Hermes as a market place for collaboration in R&D with regard to electricity networks (Hermes, 2007). This is an internet platform matchmaking instrument in which organizations in the electricity sector can describe the particular technical problems they encounter or the innovations that they wish to create. Other parties can subsequently contact the organizations and discuss how they can collaborate to solve this problem.

However, some interviewees argue that Hermes still does not work optimally[87] and it is estimated that only 10 percent of the innovative activity of network companies goes via Hermes.[88] The reason for this was not clear, but a possible reason might be that it was still in its initial stage and that the concept was not yet widely known to all actors in the electricity sector.
Furthermore, the question rises whether these new programs lead to practical innovations as it is more scientifically focused. According to a interviewee, a possible better way to induce innovation could be to hire or subsidize PhD students.[89] That is why a large number of large network companies have some PhD students that combine the PhD project – in which they work on the scientific and technological frontier – with the work at the network company. This results in spill over effects of the university to the network company (and vice versa). Furthermore, since the PhD student often is not concerned with the daily practice of the network company he or she has a lot of freedom to work on the innovative network aspects. In public programs like IOP and EOS co-financing for network companies is involved. It seems, however, that the network companies do not want to spend much on that.[90] In general, the cooperation among relevant network actors diminished after liberalization.[91] At present, there are many network companies working rather independently on the same innovation.[92]
Another aspect that has been touched upon previously is that the relation between the network technology supplier and the energy company is more formalized than before, which has resulted in more extensive contractual agreements.[93] Legal documents, rules and procedures in the contractual sphere can definitely hamper innovation. Technical specifications are further detailed and functional specifications are accompanied with guarantees and penalty clauses. With these kind of arrangements there is a tendency for technology suppliers to only provide conventional and proven technologies. Practical examples are found in the United States where actors do not dare to change the technical specifications of network components for the last 10-15 years due to legal aspects. Instead of improving existing components the technology suppliers choose to hold on to the existing components, i.e. the conventional and proven technology, and engineer an extra security element around it. This results in old fashioned products in combination with very complex security systems.[94]

10.3.2 Survey results

Table 10 presents the quantification of the identified variables impacting on innovation with regard to institutional arrangements as a result of the conducted survey. Similar to the institutional arrangements prior to liberalization the individual innovation projects score the highest on the innovation scale both for the suppliers and the network companies. The results suggest that individual research arrangements before and since liberalization stimulated most innovation. There is a slight difference between the two periods for this variable in case of the network operators with the variable since liberalization being higher. However, this difference is not significant, as is demonstrated by the Wilcoxon-test.

The variable of Hermes and network companies impacting on innovation scores as moderate. The very low value for the suppliers indicates that this group is not at all involved in this collaborative effort. This complies with the findings from the interviews. Furthermore, the arrangement under the COP and Hermes do not seem to differ that much in their impact to innovation as is indicated by the insignificance of the difference by the Wilcoxon-test.

Other collaborations (P98_other_coll) are also important to innovation, both for suppliers and network companies. The value of this variable is higher than the value of this variable prior to liberalization. The difference between other collaborations before liberalization is significant for network companies and close to significance for suppliers. This confirms the proposition of an interviewee who suggested that currently most innovation actually take place in project arrangements.[95] An example was the conductor for the Norned connection as addressed in section 10.2.[96]

The variable of 'shareholder since liberalization' is higher than the value of the variable prior to liberalization, albeit that the 95% confidence interval for the median value for the suppliers is rather large. This might be explained by the small sample size, but it could also suggest that there is little consensus regarding the impact of shareholders on innovation. The difference is significant for the network companies as we can see from the result from the Wilcoxon-test. This indicates that the shareholders since liberalization play a more positive role in their influence to innovation. This was not expected from the interviews. We also note that the value is not very high, which indicates that it is not a clear driver to innovation. The shareholder variable results of the suppliers and the network companies differ in median, but the difference in mean suggests a minor difference. Any difference for these two groups might be a result of the shorter time frame of the DSO shareholders as a consequence of being consolidated under an organization that is a player in the liberalized electricity sector.

The last variable we included in the survey is a competitive setting in order to compare this to the variable of monopoly position that applied prior to liberalization (see also section 0). The results are shown in the last row of the table. It seems that the competitive setting influenced innovation more positively as can be seen from the Z value. This complies with the increased competitive culture as we addressed in section 10.1. The Wilcoxon-test points out that the difference between monopoly and competition is significant for the suppliers category.[97] This suggests that in a competitive setting there is more an inclination to innovation for suppliers than in a monopoly setting. The type of innovation is, however, not determined through the survey.

Table 10 Statistics of variables of institutional arrangements

	Variables since liberalization						Comparison with prior to liberalization			
	Suppliers			Network companies			Suppliers		Network companies	
	Median	Mean	n	Median	Mean	n	Z	Asymp. Sig.(2-tailed)	Z	Asymp. Sig. (2-tailed)
P98_individual	4 [3,4]	3.5	21	4 [3,4]	3.4	54	.000[a]	1	-1.564[c]	0.118
P98_Hermes[1]	1 [1,2]	1.6	16	3 [3]	3.1	44	-.333[b]	0.739	-.726[b]	0.468
P98_other_coll	3 [2,4]	3.1	18	3 [3,4]	3.4	43	-1.724[c]	0.085		0.007[d]
P98_shareholder	3 [2,4]	2.8	21	2 [2,3]	2.4	53	-1.594[c]	0.111	-2.446[c]	0.014
P98_comp[2]	3 [3,4]	3.3	21	3 [3]	2.9	54	-2.419[c]	0.016	-.987[c]	0.324

Between brackets is the 95% level confidence interval for the median; a. The sum of negative ranks equals the sum of positive ranks.; b. Based on positive ranks; c. Based on negative ranks; d. Sign Test and Binomial distribution used; 1. Compared to COP; 2. Compared to monopoly.

10.4 Variables impacting on innovation with regard actors and games

10.4.1 Interview results

Large international actors

In previous decades the electricity sector has evolved from a sector of many small and local actors to a sector of a number of international big actors.[98] This holds for utilities as well as for technology suppliers. A large number of these former small technology suppliers have in the past decades either vanished or merged into big international organizations.[99] Present technology suppliers are now mainly big international players operating in international markets. Markets have gone open and technology suppliers have lost their former monopoly position which stimulated competition and R&D.[100] However, if we try to validate this with figures from ABB, a leading company in network technology, we see that in the years 1990-1999 the overall R&D was annually roughly around the USD 2,000 mln, while it was around roughly USD 1,000 mln annually from the period 2000-2008 (ABB, 1994, 2000, 2003, 2008, 2009).[101] Especially for big international companies the impact of national regulation for global research and development is small. According to the interviewee this R&D is more concentrated, i.e. less dispersed, than before.[102] Due to the relative large distance between the developer and the user – this is related to the above mentioned concentration – innovation supply does not always match local/national needs.[103] Nowadays there is no real local or Dutch industry for high voltage equipment except for some cables.[104] At lower voltages some equipment suppliers have remained.[105] This development has had its influence on the initiation of innovation activities. Whereas small actors could react quickly and act upon opportunities with regard to innovation,[106] the current bigger companies involve more people at different hierarchical levels in the organization to formally approve of, be informed of and be involved in any innovation project.[107] A related aspect that was found in literature is the general phenomenon that the high degree of coordination, control, checks and income inequality that goes along with more management diminishes the engagement and motivation of the employees to apply their knowledge, experience and skills (Kleinknecht et al., 2006). In addition, as the network companies merged and the networks under their operation became vaster the number of components grew. The large number of components makes the accompanying costs of replacing components very substantial.[108] Additionally, the degree to which testing a new technology can impact the network has grown with the merging of the actors and the interconnections of the networks. Furthermore, although network companies have grown these companies are relatively small players compared to suppliers as Siemens, ABB or Areva, so they are in a bad position to demand anything such as innovation.[109]

Low share of engineers[110]

The Dutch technology suppliers that are still producing in the Netherlands after liberalization have in general fewer engineers compared to the situation prior to liberalization.[111] This has had its impact on the innovative capabilities of a firm.[112] because Due to the reduced innovative capability in Dutch supplier organizations small-scale grass root innovations are difficult to pursue nowadays. Some interviewees state that innovation comes now mostly from the technology suppliers.[113] Companies transformed into mere sales agents or production facilities with no innovative capability.[114]

Fewer R&D/testing facilities[115]

There has been a broader trend among industries of outsourcing activities that are not considered by these industries as core business (e.g. innovation)[116]. This has also been answered by the bigger suppliers to focus more on technological solutions than on mere product innovation.[117] As mentioned above, innovations take place concentrated and at a larger distance from the eventual user.[118] Due to the lesser interaction between suppliers and net operators[119] the innovation could be classified as technology push.[120] This means that for some technologies more advanced, bigger and more expensive but also often unnecessary features were created with high costs.[121] Electronic relays are an example of this.[122] Network companies have no explicit demand for technologies with such advanced functionalities, but as there is not much choice they adopt it anyway.[123]

Professionalization and formalization

The former pioneering culture in the electricity sector has gradually changed since the 1980s into the present professional culture. This resulted in less room for personal hobby projects related to innovation.[124] Cost control and cost efficiency became important in network companies since the mid-1980s. Managers in utility companies were required to have more professional commercial and organizational skills. The professionalization also came with a more formal attitude towards the process of innovation. Whereas previously the innovation projects were informally granted on the basis of the authority of the engineer,[125] nowadays, typically formal project descriptions in business plans and cost/benefit analyses have to be submitted and formally approved of in order to proceed with an innovative project (Vlijm, 2002).[126] However, it was argued by interviewees that most current innovation initiatives are more viable compared to past innovation initiatives due to these formal procedures.[127] Another organizational development is the trend to specialization of company functions, such as the establishment or increased power of budget managers, purchase managers and asset managers.[128] These managers typically aim to minimize costs in the short term and therewith hamper (long term) innovative activity. The procurement function is allocated in a separate department or simply outsourced[129] with a mere objective of minimizing costs.[130] Most network companies nowadays have three sets of functionalities: the owner of the assets, who makes policy; the asset manager who operationalizes the policy into a tactical and operational plan; and the service provider, who executes the plans (Jongepier, 2007).[131] The task of the asset manager is also to keep costs of the assets low. Due to asset management techniques, the investments since liberalization have been fairly low.[132] Instead of periodic replacement and maintenance of assets or gut feeling the asset managers nowadays rely on statistical methods of stochastic degradation of the component for replacement and maintenance of assets.[133] Postponement of purchasing new assets, and therewith sweating current assets, is a way to meet the goal of minimizing costs. However, at the moment when investment becomes urgent, there is no time left for any innovative activity.[134] With regard to the organization of the supplier company, we observe that the marketing departments are more powerful than before. These departments aim for a guaranteed demand of their innovative technologies before the start of any innovative project.[135] This adds to the hindrances of initiating innovation projects. Additionally, at present the CEO's incentive is on short term profit and therewith not on innovation, which is typically a long term process.[136] With regard to the specialization of company functions we should, furthermore, add that innovation has very recently been more formalized with innovation departments and innovation managers.[137]

10.4.2 Survey results

For the variable of professionalization certain components were measured such as the marketing department, the incentives of the shareholders and the incentives of the CEO. These results are depicted in Table 11.[138] We first observe that for the group of suppliers a marketing department is convincingly a driver to innovation. The network companies have a much lower median, which might suggest a difference in kind of innovation. It also might be an indication of different mechanisms that operate at these different organizations, aspects to be explored in further research. The big scale of the current actor (big_scale) is valued relatively high in both groups which suggests that it is a driver to innovation. The results from the interviews suggested a gap between the wishes of the customers, e.g. the network operators, and the centralized innovation department at a large distance from the customer. Furthermore, the values of the variables with regard to the incentives for the CEO and shareholders to focus on the short term and in their personal benefit suggest that these do not stimulate (radical) innovation. This complies with the results from the interviews.

Table 11 Statistics of actors and games

	Suppliers			Network companies		
	Median	Mean	n	Median	Mean	n
marketing	4 [3,4]	3.4	19	2 [2,3]	2.5	48
big_scale	3 [3,4]	3.2	18	3 [3,4]	3.1	49
inc_shareh	2 [1,3]	2.3	16	2 [2,3]	2.4	45
inc_CEO	2 [1,3]	2.2	16	3 [2,3]	2.7	44

Between brackets is the 95% level confidence interval for the median.

Table 12 presents the quantification of the innovative activity of the relevant actors in the electricity sector since liberalization combined with a comparison with the actors prior to liberalization. We emphasize that the transformation of the actors is rather gradual, compared to policies that can be changed at an instant. Nevertheless, the table gives us an idea of the influence on the innovation. The median of the answers of the municipal companies and provincial companies seem to validate the difference in innovativeness as we have assessed from the interviews. First are the distribution system operators. The median of 3 suggest a mediocre impact on innovation. Compared to the municipal company it is substantially and significantly higher as the Wilcoxon-test demonstrates for both the suppliers as the network companies.[139] This, again, confirms the findings that the municipal companies had less innovative activity.

Table 12 Innovative activity of different actors

	Variables since liberalization						Comparison with prior to liberalization			
	Suppliers			Network companies			Suppliers		Network companies	
	Median	Mean	n	Median	Mean	n	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
P98_DSO[1]	3 [2,3]	2.7	19	3 [3]	2.9	54	-2.484[a]	0.013	-3.554[a]	0
2							-.302[b]	0.763	-.939[a]	0.348
P98_TSO[3]	2 [2,3]	2.3	19	3 [3]	2.9	44	-1.134[b]	0.257	-.655[a]	0.513
P98_supp	3 [3,4]	3.3	19	3 [3,4]	3.2	53	-1.000[a]	0.317	-1.177[b]	0.239

Between brackets is the 95% level confidence interval for the median; a. Based on negative ranks.; b. Based on positive ranks.; 1. Compared to municipal company; 2. Compared to provincial company; 3. Compared to the SEP.

This is the only difference in medians of the variables in this table that is found to be significant. The provincial company values only differ very slightly and a Wilcoxon-test value far from significance. The TSO and DSO seem to be rather similar in innovative activity although the score of the TSO is slightly lower. Compared to the variable of the SEP prior to liberalization it is somewhat higher, but not close to significance. If we take into account the means of the responses we see that the biggest value is for the supplier of technology, which suggests that this is for a major part where the innovations in the electricity sector occur. The value since liberalization is slightly lower than the value prior to liberalization, but not close to being significant, as the Wilcoxon test indicates.

10.4.3 Logic

The logic of the informal institutions has only slightly changed due to its intrinsic slowly changing features. One important new aspect is the change from long term perspective to a short term perspective and the shift to a more professional culture. This fits logically with the increased culture of cost efficiency (and its influence on innovation) and on the new regulatory structure with the x-factor construction (section 10.2). It also fits logically with the change to more professionalism and less room for unbridled experimentation. With regard to the actors in the sector we observed at both suppliers of network technology and network companies a shift from a company based on engineering, with own R&D facilities and a large share of engineers, to a company based on economics in which innovation procedures have been formalized. This is a logical fit with the other layers.

10.5 Conclusions

The results from the interviews and the survey showed us a number of important variables that impact on innovation. Examples are the authority (e.g. the CEO) within an organization that can promote innovative activity. Other variables are the culture of reliability, the share of engineers and the R&D facilities. Prominent hampering variables are the culture of conservatism, the current tendering rules and the incentives for the shareholders. If we want to increase the innovation activity of the sector we should focus on these variables impacting on innovation.

As mentioned above, the current institutional framework relevant to the sector of electricity networks in the Netherlands has some important barriers for innovation. Especially tendering procedures seem to rule out many degrees of freedom for innovation. We should, however, also note that present innovations, or innovations since liberalization, are probably also more economically viable as the selection process includes a cost-benefit analysis more often than before and consequently large-scale innovations with higher risk are less prominent nowadays. In other words, this research showed qualitatively that current innovations tend to be more incremental in type whereas prior to liberalization it tended to be more radical in type. The shorter time to market and the decrease of budgets on innovation dictates that investments should be economically viable. There seems less room for experimentation. Nowadays innovation and adoption is more out of economic interest instead of more a personal engineering interest. This means that current innovations might be more economically effective compared to previous innovations.[140] The present innovations seem to follow the direction of the regulation and therewith the regulation can be qualified as being effective. First it was on cost efficiency, and then it was on reliability. Many examples of both innovation trajectories were found. Moreover, regulation on underground cables and magnetic fields and the emergence of environmental groups are also drivers for innovation in a desired direction. These variables with regard to investments are drivers for new sensors, new cables and new electricity poles.

Due to the reliability paradigm and the intrinsic scepticism to new technology, innovations are mostly adopted after thorough testing procedures. However, tests in the actual networks seem harder to arrange in the new bigger companies than in the smaller companies among other variables due to more formal approval procedures with regard to innovative projects. It was seen that many of the current innovations take place during challenging projects. We might see a shift of innovation from research and development projects to innovations "on the project", integrating the innovation and adoption phase. A driver to this trend could be the shift from technical specifications to functional specifications in tendering documents, leaving room for innovation. The tendering variable consists of contradictory forces with regard to innovation, as we also have seen that the EU tendering regulation has been shifting the activities of suppliers towards cost efficiency instead of towards product innovation. Another important aspect is the legal issues involved in current technology supply. Legal documents, rules and procedures in the contractual sphere can hamper innovation as technical specifications are further detailed and functional specifications are accompanied with guarantees and penalty clauses. With these contractual arrangements technology suppliers tend to provide conventional and proven technologies instead of innovative technologies.

Although liberalization was expected to stimulate innovation, it is observed that many current institutions are clearly hampering innovation. The hypothesis that liberalization increases innovation is therefore not confirmed within this research. Furthermore, interviewees suggest that there is a shift from long-term radical innovations to short-term incremental innovations after liberalization. However, note that this research does not conclude that this trend in innovation can be attributed to only the shift to liberalization. Other factors, such as professionalization and the mergers in the sector play an important role as well.

In general we conclude that in the Dutch electricity networks, innovation and adoption used to be more driven by informal institutions and the actors themselves. Although interviewees described the sector as very conservative, we have seen many innovative efforts also before the start of the reforms.

We observed that the survey results were at certain points contradicting the interview results. This might be because the mechanisms identified with the interviews might only work under certain conditions, e.g. in combination with other variables. We should, however, also note that the survey and the resulting quantification of the variables might not do justice to the intricate relationships and the complexity involved in innovation (see also section 9.5).

Notes on Chapter 10

[1] As stressed in section 8.3.2, in the empirical chapters we describe the degree or extent to which a variable impacts on (radical) innovation. When describing the impact on innovation we refer to radical innovation. Although incremental innovation is also important it is regarded as the natural evolution of technology development (the base line scenario) and therewith analytically positioned at the lower end of the innovation spectrum.

[2] See section 2.4.4.

[3] Interview with NET03, held July 27, 2006.

[4] Interview with NET02, held July 24, 2006.

[5] Interview with NET02, held July 24, 2006; Interview with CON01, held August 11, 2006; Interview with NET04, held July 27, 2006.

[6] Interview with NET10, held August 10, 2006; Interview with CON01, held August 11, 2006.

[7] Interview with NET04, held July 27, 2006; Interview with SUP01, held August 1, 2006.

[8] Interview with NET08, held August 9, 2006

[9] Interview with SUP03, held August 4, 2006; Interview with NET10, held August 10, 2006; Interview with CON01, held August 11, 2006; Interview with NET13, held August 22, 2006; Interview with SUP05, held September 11, 2006.

[10] Interview with SUP02, held August 2, 2006; Interview with NET13, held August 22, 2006.

[11] Examples are the DC cable from the Netherlands to Norway (NorNed) and the HVDC Light, an innovation by ABB

[12] Interview with SUP03, held August 4, 2006. Note that the interconnector between Norway and the Netherlands (NorNed) is based on DC technology.

[13] Interview with NET13, held August 22, 2006.

[14] Interview with NET02, held July 24, 2006; Interview with SUP02, held August 2, 2006; Interview with NET13, held August 22, 2006.

[15] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[16] Interview with NET12, held August 21, 2006.

[17] Interview with NET12, held August 21, 2006; Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[18] Interview with NET12, held August 21, 2006.

[19] Interview with NET15, held August 22, 2006.

[20] Interview with NET16, held August 23, 2006.

[21] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006; Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[22] This gradual development has already been initiated before liberalization though.

[23] Interview with SUP07, held October 2, 2006.

[24] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006; Survey respondent 48

[25] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006.

[26] Interview with NET08, held August 9, 2006

[27] Interview with NET04, held July 27, 2006; Interview with NET08, held August 9, 2006

[28] Interview with SUP07, held October 2, 2006.

[29] Note that it might stimulate process innovation, i.e. the process of producing the network technology, but this is out of the scope of this research.

[30] The significance also holds in the sign test.

[31] The significance also holds in the sign test.

[32] However, only for the network companies the difference is also significant for the sign test.

[33] This is close to 3 corresponding to an institutional variable that results 'to some degree to innovation' in the Likert scale that we used.

[34] Although this directive has become effective prior to liberalization it can be classified as a measure in line with the liberalization paradigm. For this reason we choose to discuss this factor in and attribute it to the period after liberalization.

[35] A modified version is found in the new procurement directive 2004/17/EC.

[36] Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[37] Interview with NET16, held August 23, 2006.

[38] Interview with NET18, held August 24, 2006; Interview with NET08, held August 9, 2006.

[39] Interview with NET07, held August 2, 2006; Survey respondent 96.

[40] Interview with NET15, held August 22, 2006; Interview with SUP08, held October 18, 2006.

[41] Interview with SUP02, held August 2, 2006; Interview with SUP03, held August 4, 2006; Interview with NET08, held August 9, 2006, Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006. This might eventually endanger the quality of the technology as there is a tendency to use the cheapest materials. (Interview with NET15, held August 22, 2006.)

[42] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006.

[43] Interview with NET07, held August 2, 2006; Interview with SUP03, held August 4, 2006.

[44] Interview with NET16, held August 23, 2006.

[45] Interview with SUP08, held October 18, 2006.

[46] Interview with NET08, held August 9, 2006; Interview with NET17, held August 23, 2006; Interview with NET18, held August 24, 2006; Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006. However, an important aspect is that network companies do not want a huge variety of components/sub systems as it makes working routines harder. This standardisation of the components makes innovation difficult and standard safety procedures and requirements reduce the innovative space in innovative projects (Interview with NET18, held August 24, 2006.).

[47] Interview with NET02, held July 24, 2006.

[48] Interview with NET08, held August 9, 2006

[49] Interview with NET03, held July 27, 2006; Interview with SUP05, held September 11, 2006.

[50] Interview with NET15, held August 22, 2006; Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[51] Interview with SUP03, held August 4, 2006.

[52] Interview with NET02, held July 24, 2006; Interview with SUP03, held August 4, 2006.

[53] Interview with SUP03, held August 4, 2006.

[54] Interview with NET02, held July 24, 2006.

[55] Interview with SUP03, held August 4, 2006; Interview with CON01, held August 11, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[56] This statement suggests that the link between innovation and reliability is too weak to have the costs of innovation covered under the current regulation.

[57] Interview with NET19, held September 21, 2007; Interview with NET11, held August 15, 2006.

[58] Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006.

[59] Interview with NET01, held April 10, 2006; Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[60] Interview with SUP02, held August 2, 2006.

[61] Interview with SUP03, held August 4, 2006.

[62] As the international schemes, e.g. European Framework Programme 7, were not prominent during the interviews these international schemes were not included in the survey.

[63] In Dutch: 'Innovatieve Ontwikkelingsprojecten'.

[64] In Dutch: 'Elektro Magnetische Vermogens Elektronica'.

[65] In Dutch: 'Meerjarige Collectieve Opdracht'.

[66] These regulations are not specifically attributable to liberalization or to the period after liberalization. These regulations and the resulting innovations are, however, typical issues that play a role in the current innovations of electricity components.

[67] Due to the decreased number of municipality workers the chance to winning a legal case on expansion of the network have become more in favor of the public opposition (Interview with NET02, held July 24, 2006.).

[68] Interview with NET05, held August 1, 2006; Interview with SUP03, held August 4, 2006.

[69] Interview with SUP03, held August 4, 2006.

[70] Interview with SUP03, held August 4, 2006.

[71] Interview with NET07, held August 2, 2006; Interview with SUP03, held August 4, 2006; Interview with NET08, held August 9, 2006, Interview with NET18, held August 24, 2006.

[72] Interview with NET03, held July 27, 2006.

[73] Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006.

[74] We note that the environmental regulation is not a variable in the survey, as it became only prominent in the last series of interviews when the survey was already partly conducted.

[75] The xq tariff regulation for suppliers is close to being significant with value 0.056. For the network operators also the sign test demonstrates significance, whereas for the suppliers the sign test does not prove significance of any of the two variables.

[76] Survey data (respondent 88).

[77] Survey data (respondent 77).

[78] Interview with NET10, held August 10, 2006.

[79] Interview with SUP07, held October 2, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[80] Interview with NET10, held August 10, 2006; Interview with CON01, held August 11, 2006; Survey respondent 85

[81] Interview with SUP01, held August 1, 2006.

[82] We refer to section 9.1 for an elaboration of the collaborative culture.

[83] See section section 0 for a discussion on this collaborative research program

[84] In Dutch: 'Programma Elektriciteitsnetwerk Gebruikers Onderzoek'.

[85] A list of projects can be found in Ongkiehong, 2006

[86] In Dutch: 'Energie Onderzoek Subsidie'.

[87] Interview with NET01, held April 10, 2006; Interview with SUP02, held May 5, 2008.

[88] Interview with NET01, held April 10, 2006.

[89] Interview with NET17, held August 23, 2006.

[90] Interview with CON01, held August 11, 2006.

[91] Interview with NET09, held August 10, 2006.

[92] Interview with SUP02, held May 5, 2008.

[93] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006; Interview with SUP08, held October 18, 2006; Interview with SUP09, held October 18, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008. According to a supplier of IT technology there has also been differentiations in contracts with customers with regard to availability (survey respondent 26).

[94] Interview with SUP05, held September 11, 2006.

[95] Interview with SUP03, held August 4, 2006.

[96] We note that prior to liberalization innovations also occurred during projects. An example of previous innovations during projects is for instance the connector to cross the waters of the Westerschelde. in the province of Zeeland as around 1958 described by Buiter ((1994). The conductors needed to withstand (anchoring) ships and therefore the reinforcement of the crossing was executed with one three phase cable instead of multiple cables to limit the chance of being hit by a ship. Furthermore, a special cage boot was engineered as a steel construction especially for this electrical crossing.

[97] The sign test do not show significance.

[98] Interview with NET02, held July 24, 2006; Interview with SUP03, held August 4, 2006.

[99] Interview with NET13, held August 22, 2006; Interview with NET02, held July 24, 2006; Interview with SUP03, held August 4, 2006; Interview with SUP05, held September 11, 2006.It also holds for KEMA as can be seen in EN, 2008c.

[100] Interview with SUP03, held August 4, 2006; Interview with SUP07, held October 2, 2006.

[101] This could also be partly attributed to the divestment of some major parts of the company around 2000. However, if we try to discount that factor by relating the R&D expenditures to the turnover (revenues) we see a clear difference ranging from around 8% of the revenues in R&D in the 1990s to around 4% of the revenues in R&D annually since 2000.

[102] Interview with NET02, held July 24, 2006; Interview with SUP02, held August 2, 2006; Interview with SUP03, held August 4, 2006; Interview with NET08, held August 9, 2006

[103] Interview with NET02, held July 24, 2006.

[104] Interview with SUP04, held August 18, 2006.

[105] Interview with NET05, held August 1, 2006; Interview with NET06, held August 1, 2006; Interview with SUP04, held August 18, 2006.

[106] Interview with NET01, held April 10, 2006.

[107] Interview with NET10, held August 10, 2006.

[108] Interview with NET02, held July 24, 2006; Interview with SUP01, held August 1, 2006; Interview with NET16, held August 23, 2006.

[109] Interview with SUP09, held October 18, 2006; Interview with NET10, held August 10, 2006; Interview with SUP03, held August 4, 2006.

[110] We included the low share of engineers in our description of the interviews to make a contrast with the variable prior to liberalization. However, as we only considered the 'the dominant share of engineers' as an important driver to innovation we excluded the low share of engineers in our quantitative assessment.

[111] Interview with NET08, held August 9, 2006, Interview with SUP09, held October 18, 2006.

[112] Interview with NET20, held February 20, 2008; Interview with NET21, held February 20, 2008.

[113] Interview with NET03, held July 27, 2006.

[114] Interview with NET02, held July 24, 2006; Interview with SUP05, held September 11, 2006.

[115] We included the variable of 'Less R&D/testing facilities' in our description of the interviews to make a contrast with the variable prior to liberalization. However, as we only considered the 'presence of R&D/testing facilities' as an important driver to innovation we did exclude the less R&D/testing facilities in our quantitative assessment.

[116] Interview with SUP07, held October 2, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.

[117] Interview with SUP02, held August 2, 2006; Interview with SUP07, held October 2, 2006.

[118] Interview with NET02, held July 24, 2006; Interview with SUP07, held October 2, 2006.

[119] Interview with NET02, held July 24, 2006.
[120] Interview with SUP01, held August 1, 2006.
[121] Interview with SUP01, held August 1, 2006.
[122] Interview with SUP01, held August 1, 2006; Interview with NET10, held August 10, 2006.
[123] Interview with NET01, held April 10, 2006; Interview with NET02, held July 24, 2006; Interview with NET17, held August 23, 2006.
[124] Interview with NET08, held August 9, 2006
[125] Interview with NET09, held August 10, 2006.
[126] Interview with NET08, held August 9, 2006, Interview with NET09, held August 10, 2006; Interview with NET15, held August 22, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.
[127] Interview with NET12, held August 21, 2006; Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.
[128] Interview with SUP10, held February 22, 2008; Interview with SUP11, held February 22, 2008.
[129] Although you also see from the procurment department the functional specifications as availability and interruption risks. This way you do not eliminate new technologies (Interview with NET08, held August 9, 2006).
[130] Interview with SUP05, held September 11, 2006; Interview with SUP06, held September 11, 2006.
[131] Interview with NET07, held August 2, 2006; Interview with NET13, held August 22, 2006; Interview with NET16, held August 23, 2006.
[132] Interview with SUP03, held August 4, 2006.
[133] Interview with NET04, held July 27, 2006; Interview with NET09, held August 10, 2006; Interview with NET10, held August 10, 2006; Interview with NET11, held August 15, 2006; Interview with NET02, held July 24, 2006.
[134] Interview with NET18, held August 24, 2006.
[135] Interview with NET02, held July 24, 2006.
[136] Interview with NET02, held July 24, 2006.
[137] Interview with NET01, held April 10, 2006; Interview with NET10, held August 10, 2006.
[138] The variables from the interviews do not fully correspond to the variables included in the survey. For some variables we included the opposite variable of in our description of the interviews to make a contrasting comparison with the variable prior to liberalization, such as for the variables less engineers and less R&D/testing facilities and for professionalization and formalization. These variables were, however, not included in our quantitative assessment.
[139] The significance also holds in the sign test.
[140] Interview with NET12, held August 21, 2006; Interview with NET15, held August 22, 2006; Interview with SUP07, held October 2, 2006.

Part 4 Synthesis

11 Conclusions

In this chapter we answer the main research question: What are important variables in the modernization of electricity networks in the Netherlands from both the alignment perspective and the innovation system perspective? We summarize the empirical findings as presented in Part 2 and Part 3 of this research and draw conclusions.

11.1 Alignment perspective

With regard to the alignment perspective the following question was posed in section 3.1:

What are important variables in the modernization of electricity networks in the Netherlands from the alignment perspective?

Focal points pertained to the role that alignment has played in the modernization of the electricity networks and the role of the critical functions of the electricity system (see section 4.3, 5.3, 6.3 and 7.3). We applied the alignment framework to a number of historical modernization processes and found that alignment can act as an important explanatory variable in understanding these modernization processes. Furthermore, the concepts of alignment and critical functions enhance our understanding of the infrastructure system as a system with certain functions that have to be fulfilled to attain the desired performance of the electricity system.[1] In Part 2 of this thesis we identified the following important variables in the modernization of electricity networks:

- Alignment can act as an important variable impacting on modernization in the case of network expansion and reinforcements as addressed in sections 4.2.2, 5.2.2 and 5.2.5;
- Misalignment of institutions and technology can act as an important variable impacting on modernization, in case of network adaptation as addressed in section 6.2.1, 7.1.2 and 7.2.2;
- Modernization, i.e. technical adaptations can act as an important variable impacting on the alignment between institutions and technology as addressed in section 6.2.1 and 7.2.2 and between between technology and technology like in section 6.2.2;

- Modernization i.e. interconnections and other technical adaptations can act as an important variable impacting on misalignment as addressed in section 4.2.1 and 7.1.2.

This implies that the several sub questions as posed in section 3.1 are answered affirmative. However, it is under specific circumstances that these relationships occur. We use the results of Chapters 4 to 7 to address this issue in answering the research question more thoroughly in the following paragraphs.

11.1.1 Alignment as a driver to modernization

We observed a number of examples in which the alignment of the institutions and technology (critical functions) acted as an important driver to modernization (e.g. section 4.2.2). We discussed, for example, the critical function of long term capacity management as a means to align the generation function with the consumption and network functions. In other words, the growing consumption had to be acted upon by growth in generation and network capacity. Cases show that capacity management was institutionally coordinated and hence led to network modernization. Examples of such institutions are the concession scheme for provinces and the Obstruction Act (section 5.2.2), which were directed at long term capacity management and which drove the modernization, i.e. electrification of the Netherlands. Another example of alignment as a driver to modernization relates to the normalization and standardization organisations that were erected (addressed in section 5.2.5). These new institutional rules on technological standards acted as a driver for the interconnection of individual small networks into a bigger electricity network and therewith contributed to modernization of the electricity system.

From the examples above it is clear that the capacity management, interconnection and interoperability have a strong relationship with modernization. Especially the long term capacity management is involved with the long term capacity of the different elements of the electricity network. In other words, if the critical function of capacity management is aligned with the institutions, the building of the new network and generation (i.e. modernization) follows from the increased consumption of electricity. Furthermore, it seems obvious that interconnection of different electricity networks can only occur in case that specific technical parameters are coordinated so that interoperability is safeguarded. In other words, institutions have to be aligned for the facilitation of interconnection and interoperability to make modernization happen, in this case the integration or interconnection of fragmented networks.

11.1.2 Misalignment as a driver to modernization

In chapters 4-7 we observed ample historical examples that demonstrated that the misalignment of institutions and technology played an important driving role in the modernization of electricity networks. Hence, the sub question 'Can misalignment act as a variable impacting on modernization?' is answered affirmative. In this section we will highlight three of the identified examples: an example where misalignment of institutions and technology was unforeseen, an example where misalignment between institutions and technology was foreseen and an example that can be perceived as a technical misalignment issue.

The first example is the interconnection of the network with Germany leading to misalignment and to the implementation of phase shifters in the system (section 7.2.2). Modernization through international interconnection led to misalignment in combination with the German windmills. The international technical scope and the national institutional scope did not match and were thus not aligned, which caused unexpected and undesired electricity flows over the Dutch electricity network. Furthermore, the reaction to this problem, i.e. the installation of the phase shifters was a modernization action to make the technical scope national and therewith realign the technical with the institutional scope. The example indicates that misalignment was unforeseen and immediate action was needed at the time of the unwanted currents in order to avoid blackouts.

Next to this situation of unforeseen misalignment there are foreseen misalignment situations resulting in modernization, which will be elaborated in the next example. As addressed in section 2.4.4 co-evolution theories (e.g. Perez, 2002; Tunzelmann, 2003) often imply an evolutionary process with a equilibrium (i.e. alignment) as a starting point, a change which turns the system in disequilibrium being a discontinuity, followed by an action related to institutional or technical change (i.e. realignment) that makes the system in equilibrium again. We observed that the alignment process does not always follow this procedure. We stress that in some situations misalignment can be foreseen and anticipated and hence disturbances of the system can be avoided. An example of this foreseen misalignment relates to the abolishment of the SEP (addressed in section 7.2.3). To cope with this abolishment and the resulting misalignment modernization was initiated. For example, technical adaptations in the network were executed such as controls for balancing and capacitor banks for the reactive power. As an institutional change a new organization was established (Tennet) in order to coordinate specific critical functions of the electricity system. In this case there was no discontinuity as the actors knew in advance that the critical functions had to be addressed with the abolishment of the SEP. There is no learning involved as common in evolutionary processes as technically it is certain what are the subsequent steps to reach a new alignment (equilibrium).[2] The mental maps of the different actors with regard to this issue are alike and uncertainty is low.[3] This is important in our analysis of alignment as this suggest that in order to perform a sound historical analysis we should not only identify the situations of alignment and misalignment, but we should dig deeper and additionally identify situations that have a potential for misalignment in order to understand technical adaptations of the network and the establishment of the Tennet.

The third example is the increasingly bigger scale of generators under the 'economies of scale' paradigm (addressed in section 6.2). This technical issue was dealt with by higher voltage conductors of 380 kV, an example of technical adaptation of the network in order to cope with a possible misalignment with regard to capacity management. The electricity network function can be qualified in LTS terms as the reverse salient that has to be adapted in order to have it aligned with the large electricity system.

These examples demonstrate that the misalignment is an important driver for modernization as it triggers actors to act. The question arises what the conditions are under which this relationship of misalignment as a driver to modernization holds. The above examples indicate a certain need and urgency to solve the misalignment in order to maintain the system's integrity. Especially the critical function of real time capacity management is prominent in the examples. With regard to the second example of abolishing the SEP, we argue that the capacity management real time can either be institutionally safeguarded by central coordination (as was done by the SEP), or by modernizing the system and deploying capacitor banks and other technical equipment to technically coordinate the capacity real time. In case of ample experience with the critical functions of the system, it seems obvious how certain institutional change, i.e. the abolishment of the SEP, needs to be addressed in order to maintain the system's integrity. In these cases there is no actual misalignment before a new aligned situation is reached. This is, however, not the case in the first example in this section related to international interconnection. This example suggests that in cases where multiple actors are involved with different mental maps uncertainty is high. The international aspect (the different national rules and objectives) further complicates the issue. Hence, it is foreseen that it would take a long time and a lot of effort to align the actors in order to come to an institutional change. In such cases it can be more efficient and effective to choose for technical solutions.

11.1.3 Modernization as a driver to alignment and misalignment

In this paragraph we discuss whether there are circumstances or conditions under which modernization acts as a driver to the (mis)alignment in the system. We observed a number of cases where modernization of the electricity network played a driving role in determining the alignment of institutions and technology. One example, also previously addressed, relates to the implementation of phase shifters to restore or safeguard the alignment by blocking the unwanted electricity currents from German windmills and the deployment of capacitor banks to achieve a new aligned situation (section 7.2.2). Modernization in this sense can be regarded as a technical solution to a misaligned situation.

The condition for modernization to be a driver for alignment is in cases where the technical adaptation is the solution for a (foreseen) misaligned situation. The (foreseen) misalignment might also be answered by an institutional change. However, as discussed in section 11.1.2 institutional change might be more costly or too time consuming. Aligning different actors with different objectives might be costly in time, money and effort, so that it would be more appropriate to have a technical solution in place to deal with the urgent misaligned system.

Next to modernizations in which the system became re-aligned, we identified cases in which modernization of the network was a driver for misalignment of the system. An example is the shift to AC technology which involved the new essential function of load balancing (addressed in section 4.2). This critical function was acted upon prior to any major collapse of the system – an example of foreseen misalignment – by the necessary institutional and technical adaptations. Another example is the development of interconnections and cooperation of interconnected networks which raised interoperability and interconnection issues. The interconnection with the German grid and the uncontrolled/uncoordinated electricity generation by the German wind mills led to a situation of misalignment which threatened the reliability of the Dutch network (7.2.2). These issues are examples of modernization that resulted in misalignment of the system which needed to be resolved by intuitional or technological measures.

We observed that aspects of the electricity network such as the change in generation function or the change in consumption function are also important causes of misalignment. For example, we observed in section 7.2.1 that a change in generation function, which can be the implementation of DG has, among other results, an impact on the alignment with regard to capacity management (e.g. frequency stability). Similarly and following up on the previous paragraphs we observed in section 6.2.2 that the modernization of the system, by increasing the system to the 380 kV level to allow for larger transports from the increasingly large generation plants, made the system more aligned technically as the three parts of the value chain – generator, network and load – were now in such a way constructed that it was in balance and that the system could adequately work as a whole. This is an example where modernization has led to the (technical) alignment of the system.

In sum, we observed that under certain conditions modernization can act an important variable to alignment and to misalignment. The former can be the case when certain technological adaptations to the system result in an increased importance of certain critical functions, such as with the shift from DC to AC (see section 4.2) or when certain high voltage levels need reactive power control (see section 6.2). Especially with an intertwined network adaptations of the system can induce critical functions in the system that need to be coordinated. Due to the complexity of the network and the different institutional scopes involved not every possible impact on the system can be foreseen. Additionally, under conditions when parts of the value chain have to be aligned with to changing capacities in other parts of the chain modernization can act as a driver to the alignment of the system as is demonstrated with the implementation of the phase shifters.

11.1.4 Regularities

A regularity that was observed in our historical analysis relates to the network expanding to larger scales by means of interconnections: from a local to a regional system, from a regional to a national system, and finally from a national to an international system.[4] These modernizations were accompanied by an increased technical scope and capacity management issues (e.g. section 5.2.5 and 7.2.2). These new interconnections involved setting norms and standards to enable connection and operation with new actors. Next to these critical functions that can possibly be expected from the outset, we found functions that were less straightforward. These functions were inherent to new technologies that accompanied the expansions. For example, a local system in the 19th century was either DC or AC. A regional system was typically AC, which brought about the function of balancing or short term capacity management (section 4.2.1). Another example is the expansion to a national system which was accompanied with a rise in tension to 380 kV. This brought about specific essential functions with regard to reactive power and system management (section 6.2.2). Technologies are not always simply scalable in size. Higher voltages require new and innovative components. For example, initially switches were developed with air for usage at low voltage levels. However, with higher voltage levels air would not suffice so oil baths were required for the switches. Scaling with even higher voltages was not possible as the oil would burn. To overcome this salient switches with inert gases were developed.[5] In conclusion, next to some regularities that accompanied the expansion to different technical scopes, other technical functions manifested themselves with new technologies, larger technical scope and higher voltages. In other words, not every technical function could be easily forecasted with the growth of the electricity system. Some technology specific functions were not to be foreseen based on previous electricity network modernizations. This implies that unexpected misalignment issues could have resulted from that. It also implies that with current modernization efforts, still unexpected issues can arise that would jeopardize the electricity system. This understanding is important and deviates from the standard engineering and policy making approach which is based on the idea that the system can be designed. Our approach shows that the electricity network should be understood as a complex socio-technical system with intricate interrelationships.

11.1.5 Logic

We built our conceptual framework of the alignment perspective with different layers of institutions to find a logic within the institutional layers in the process of modernization.[6] This logic is important to understand the role of each layer in the modernization process and to understand the relation with other institutional layers. The layered approach resulted in an inventory of institutional coordination mechanisms that give shape to the institutional system and with which to explain the alignment with the technology (see section 4.1.2, 5.1.2, 6.1.2 and 7.1.2). This is summed up in Table 13.

	Period 1 Shift to alternating current	Period 2 Electrification	Period 3 Reinforcement and interconnection	Period 4 Shift to hybrid system
Informal institutions	Electricity as luxury good	Electricity as universal service, reliability	Economies of scale, energy as crucial to economic development, reliability	Liberalization, Economies of scale, sustainability, cost efficiency, reliability
Formal institutions	At local level	At provincial level	Electricity Act 1 Regulation	Electricity Act 2 and 3, Net Code, Regulation
Institutional arrangements	Contracts between consumers and energy companies and concessions from municipalities to private companies	Concessions from national to provincial government, concessions from provincial government	Institutional arrangement of collaborating production companies (SEP)	Collaboration agreement, Structure Scheme Electricity Supply
Actors and games	Small private companies, municipalities	Provinces, provincial energy companies, municipal energy companies	SEP, provincial energy companies	SEP, Tennet, large production and supply companies, regulated network companies, local electricity companies

Table 13 Institutional logic in alignment perspective

The table shows an evolution in the logic of the electricity system from institutions directed at small scale local level in period 1 to institutions directed at an integrated electricity system in period 4. Another important evolution which was also identified in the innovation system perspective in Part 3 of the research (section 9.4.3 and 10.4.3) is the shift from a technical focus with reliability as a prime driver to an economic focus with cost efficiency as a prime driver (section 6.1.2 and 7.1.2). We also observed that a shift to another logic can be initiated at different institutional layers. For example, in period 1 the institutional arrangements, the formal institutions and the informal institutions were taking shape as a result of the grass roots initiatives by the actors at local level. This institutional layer thus determined the logic of the rest of the institutional layers. The logic of the system can also be determined by the informal institutions, the public values, which trigger other parties to act. This can be either the government at national, provincial or municipal level or private actors. An example is the electrification of the system which is driven by the public value of universal service of electricity. We see that the institutions at other layers are directed at electrification of the Netherlands to facilitate this universal service value.

11.2 Innovation system perspective

In this section we address the main research question with regard to the innovation system view as posed in section 8.1:

What are important variables in the modernization of electricity networks in the Netherlands from the innovation system perspective?

This research question is divided into two sub questions. First, which were important institutional variables impacting on innovation prior to liberalization? Second, which are important institutional variables impacting on innovation since liberalization? These questions were addressed in Part 3 of this study (Chapters 9 and 10). We elaborate on the main conlusions in the following.

11.2.1 General conclusions

The empirical research showed us the innovation before and since liberalization. The research indicated that the municipal companies lagged behind in innovative activity prior to liberalization. Current DSOs are mediocre in innovative activity. Most innovative activity occurs at the supplier of network technology. This last argument holds prior to and since liberalization. Although liberalization was expected to be stimulating innovation, it is observed that many current institutions are clearly hampering innovation. The hypothesis that liberalization increases innovation is therefore not confirmed with this research. Furthermore, interviewees suggest that there is a shift from long-term radical innovations to short-term incremental innovations after liberalization. However, this research does not suggest that this innovation trend can be fully attributed to liberalization. Other variables, such as professionalization and the mergers in the sector play an important role as well. These variables can not be unambiguously attributed to either the period prior to or the period since liberalization (addressed in section 8.4).
Although the sector was described as very conservative and hence little innovative, we identified a number of institutional variables that offset this variable of conservatism. Moreover, a number of innovations prove that the sector is less conservative than often assumed. Examples of innovations in the past and present are the XLPE cables, the electromagnetic relays and subsequently the digital relays, the electromagnetic switches and Wintrack. We observed that the informal institutions towards innovation are historically driven and dependent on the critical mass of innovating engineers within the organizations. The direction of innovation has mostly been either a result of personal interests of innovators or as a big joint effort of companies.

It was argued that the grass roots innovations, i.e. the bottom up initiatives, did not per se lead to technically sound and economically sound systems. These uncoordinated bottom up initiatives resulted in a situation of different standards among networks. This lack of standardization hampered connection of networks and the exchangeability of components.[7] Moreover, there has been a trend of expanding functions of a component as the innovation was driven by engineers.[8] Some technologies became more advanced, bigger and more expensive, instead of simpler and cheaper. However, next to the uncoordinated bottom up initiatives we discussed the coordinated innovation efforts such as the COP. Also for this variable it was argued that the economic feasibility of the innovations were at times questionable. This suggests that both the bottom up and the more top down innovation initiatives prior to liberalization were often not economically feasible. This is confirmed by the findings in the interviews that suggested that money was not a big issue with regard to network technology. It is suggested that present innovations are probably more economically viable (i.e. with a shorter pay back period), as the selection process with cost-benefit analysis is currently more applied than before for innovative projects. It was found that long term innovations with higher risk are less prominent nowadays. The shorter time to market and the decrease of innovation budgets dictates that investments should be economically viable and that there is less room for experimentation. Nowadays innovation is more out of economic interest, so there are more profits from current investment in innovative activity than previously.[9] To cover the risks that are accompanied with innovations more often than before contractual arrangements between the technology supplier and the network company are used. With these contractual arrangements there is a tendency for technology suppliers to only provide conventional and proven technologies. This influences radical innovation negatively.

The identified institutional variables are highly interrelated across different institutional layers. An example of this interrelationship is the obvious link between the dominant share of engineers and the pioneering culture within organization variables, variables at the layer of actors and games and at the informal institutional layer respectively. Additionally, in Chapter 9 we discussed that the variable of a monopoly position alone cannot fully explain the innovative activity, but only in combination with the variable of prestige for innovation. Again these are variables at different institutional levels. In sum, a logical combination of institutional variables (referred to as the logic), possibly at different layers, such as the prestige of innovation, is needed to fully understand the drivers in the modernization process (provided in section 11.2.2). These interrelationships, furthermore, suggest that the combination of variables might be more persuasive in explaining innovative activity than individual variables.

For some variables it is not clear from the outset whether they acted as a driver or barrier to innovation such as the variable of culture of network reliability. It was discussed that there were network reliability arguments to keep using proven conventional technology, which implies that the culture of reliability influenced innovation negatively. However, numerous other examples provided evidence for the statement that the culture of reliability of the electricity network influenced innovation positively (section 9.1). Another example is the culture of cost efficiency that can impact on innovation both negatively and positively, the net result can be determined quantitatively. Although a number of variables are not strictly a driver or barrier, the description of the arguments of the variable in the positive or negative direction towards modernization contributes to an understanding of its relation in the modernization process. Moreover, the quantitative assessments give an indication of its net contribution to innovation, albeit that in the complexity of innovation processes the quantification of these variables cannot mechanically be transformed into policy recommendations. Reality is too complex to be boiled down to a set of individual factors to innovation. The quantitative approach can, however, serve as a starting point for further research disentangling the relationships with regard to the most important variables impacting on innovation. In combination with the qualitative approach the quantitative approach enhances our understanding of the important variables in the modernization from an innovation system perspective. As mentioned in Chapter 10 the survey results were at certain points contradicting the interview results possibly because the mechanisms identified with the interviews might only work under certain conditions, e.g. in combination with other variables. We therefore emphasize that the survey and the resulting quantification of the variables might not do justice to the intricate relationships and the complexity involved in innovation (see also section 9.5). On the other hand, the quantitative assessment can act as a means to determine which variables need further exploration, for example, by additional interviews.

11.2.2 Logic

In Table 14 we present the identified institutional variables that fit with the main characterization of the period prior to and since liberalization. The empirical study showed that the highest impacting values for the institutional variables prior to liberalization are in the categories of the informal institutional variables, i.e. reliability and long term mindset, and the variables with regard the actors and games, i.e. share of engineers, authority of innovative persons and R&D.[10] The logic of the informal institutions in this period is one where a number of norms and values are in line with each other. The conservatism logically fits with value of reliability. The pioneering and prestige of technology are also in line with each other. The collaborative culture works well with the pioneering culture and the reliability aim. The cost efficiency is part of the informal institutions of the system. However, we also notice that a number of informal institutions do not work in the same direction, such as the pioneering/prestige of new technology and the conservatism. From the survey and the interviews we found that the institutional layers of informal institutions and actors and games were dominant in determining the innovative activity of the electricity sector. These two institutional layers are in line with each other. In other words, it was the culture and the actors that predominantly determined the innovation. It, furthermore, suggests and confirms that the sector was largely self-regulated in setting out the technological trajectory and that the intervention from the national government did not substantially enhance the innovative activity of the sector.

	Prior to liberalization	Since liberalization
Informal institutions	Culture of pioneering, long term perspective	Culture of professionalism, short term perspective
Formal institutions	(Regulation)	Net Code, regulation
Institutional arrangements	(COP)	(Hermes)
Actors and games	Engineering based companies	Economics based companies

Table 14 Institutional logic in innovation system perspective
Institutions between brackets have a minor influence

Since liberalization a number of informal institutions has only slightly changed due to its intrinsic slowly changing features. One important new aspect is the change from long term perspective to a short term perspective and from a culture of pioneering to a more professional culture (also addressed in section 11.1.5). This fits logically with the increased culture of cost efficiency (and its influence on innovation) and on the new regulatory structure with the x-factor construction (section 10.2). It was shown that the highest values in this period are in the layers of the informal institutional variables, the institutional arrangements and actors and games. Regarding the latter layer we should also include the general variables authority of an innovative person in an organization. That is why we can conclude that both institutional layers, i.e. the informal institutions and actors and games, still hold since liberalization as they did prior to liberalization. Beside the large value of the variable of individual projects in the layer of institutional arrangements there are no large values in the other layers. The layers of the informal institutional variables and the variables with regard to actors and games influence the innovative activity positively. Regulation from the central government does not seem to play a large role as with the situation prior to liberalization. Self regulation with regard to innovation still seems a good characterization of the electricity sector.

Notes on Chapter 11

[1] This holds for a stable system, but also for a system in transition to another system. For example, from the illustrations in Part 2 we learned that in modernization the technology changes but the institutions might change likewise. On the other hand, large institutional changes might be accompanied by large technical changes. An example is the modernization to a hybrid system which coincided with the liberalization of the electricity system.

[2] This resembles the neoclassical economic approach in which the developments are conceived at one equilibrium to the next as the transactions that occur at equilibrium prices, and in which the process from one equilibrium to the next is left out of the analysis. No inter equilibrium prices are assumed as this would impact on the prices in the next equilibrium.

[3] Terms are addressed in section 2.3.

[4] We acknowledge that this is a stylized representation of history and that this does not always applies to every country's electricity system development (Jonker, 2008a).

[5] Interview with NET11, held August 15, 2006.

[6] The concept of logic is explained in section 2.3.

[7] Interview with NET02, held July 24, 2006.

[8] Interview with SUP01, held August 1, 2006; Interview with NET17, held August 23, 2006.

[9] Interview with NET12, held August 21, 2006; Interview with NET15, held August 22, 2006; Interview with SUP07, held October 2, 2006.

[10] These variables with regard to actors and games are actually in the survey presented as general variables to innovation not specifically attributed to the situation prior to liberalization. As most of these variables are relevant prior to liberalization we attributed these to that particular period. This does not mean that these variables are not relevant since liberalization.

12 Discussion

In this chapter we elaborate on the implications and limitations of this research. We start with the scientific implications and limitations of the alignment perspective. Then we address the implications and limitations of the innovation system perspective and discuss how both analytical frameworks complement each other. Subsequently, we address some practical implications of this research from both analytical perspectives and make some suggestions for further research.

12.1 Scientific implications

12.1.1 Alignment perspective

In Part 2 of this dissertation we presented a historical analysis of the modernization of the electricity system from an alignment perspective to further investigate the nature of the co-evolution of institutions and technology. Next to building on the LTS approach where technical alignment is a focal point, we built on the coherence approach focusing on the link between institutions and technology. Whereas existing coherence literature uses a static comparative approach, we used a longitudinal approach and added a socio-technical context to the specific relations in the modernization processes. This allowed for insight into the dynamics, e.g. sequential relationships, and a better understanding of the variables and relationships involved in modernization and alignment. The research as a whole contributed to the formulation of hypotheses[1], or patterns of relationships, relevant to alignment and modernization, an important step towards a better understanding of modernization as elaborated in section 11.1. Moreover, a better understanding of the co-evolution process, as a result of our research, is a new step in finding the conditions for change either in the direction of institutional change or technical change. We built our conceptual framework of the alignment perspective with different layers of institutions and based on insights from NIE and OIE (section 2.3) to find an 'institutional' logic in the modernization of the electricity networks (section 11.1.5 and 11.2.2). This logic proved to be important to understand the role of each layer and the interrelationships of these layers in modernization. The layered approach also resulted in an inventory of institutional coordination mechanisms with which to explain the alignment with the technology (inventory in section 11.1.5).

Although coherence theory makes a distinction in economic performance, technical performance and public values (e.g. Finger et al., 2005), existing coherence literature has primarily focused on the technical performance of the system. Current theory on coherence, furthermore, misses a framework for assessing the trade offs between economic performance, technical performance and public values. In our research we incorporated these trade offs by describing them in our socio-technical context and in our analysis, we treat these trade offs as endogenous variables of the model (e.g. section 5.2.1). Where appropriate we explained the institutional and technical adaptation of the system driven to improve the performance not only from a technical, but also from an economic or public values perspective. This has given us a better understanding of the drivers in modernization and it has demonstrated that the aspects of economic performance and public values are important determinants in modernization. A next refinement could be to further formalize the trade off aspect of the performance into the existing conceptual model, which would enhance the understanding of the drivers in the process of modernization and alignment.

12.1.2 Innovation system perspective

In Part 3 of this dissertation we discussed the important variables in the modernization of the electricity networks from an innovation system perspective. We applied the analytical framework of the innovation system and used the institutional layers (Figure 10) to categorize the important institutional variables impacting on innovation. It, furthermore, allowed for assessing the logic in modernization, which contributed to the understanding of the interrelations of the four institutional layers. We stress that a logic combination of institutional variables, possibly at different layers, such as the prestige of innovation combined with a monopoly position is needed to fully understand the innovative activity. These interrelationships implicate that the combination of variables might be more persuasive in explaining innovative activity than individual variables. In evolutionary game theory as developed by Aoki (2001) different interrelated domains are distinguished: the social, political, judicial and economic. The distinction is similar to our Figure 10. It is stressed by Aoki and also North (1990; 2005) that the different domains are connected: changes in the political domain need to be accompanied in the judicial domain and vice versa. Likewise changes in the social domain need to have their corresponding adjustments in the other domains. If this would not be the case misalignment would result between the domains and the logic of the system would be distorted. North discusses specifically the differences in the speed of change between the different domains which makes an effective design of institutions simultaneously in different domains of the system challenging. The concept of so-called linked games connects to polycentricity in the work of Ostrom (1972). Polycentrism means more than just different centres of decision making operating in competition with each other in a specific domain. Polycentricity is a complex system of powers, values and rules which creates a dynamics of the system as a whole due to the need of certain alignment between the different domains. If that alignment, the logic, is distorted then a tension is created in the system which triggers adjustments in part of the systems to restore the logic. "Market polycentrism seems to entail judicial polycentrism, judicial polycentrism to entail political polycentrism, political polycentrism to entail constitutional polycentrism. If one accepts the logic of such a systemic logic, one may visualise the entire social system shaped by underlying currents originating in pulsating polycentric domains. Any island of polycentric order entails and presses for polycentrism in other areas, creating a tension towards change in its direction." (Aligica and Boettke, 2009: 26).

The innovation system perspective proved to be a good starting point in our explorative research to understand the innovative aspect of modernization Furthermore, the addition of the innovative capabilities at the institutional layer of actors and games proved useful to capture important variables impacting on innovation positively. However, along the way we encountered a number of variables that could not qualify as institutional variables (or innovative capabilities) in the innovation system perspective such as the demand of electricity and the up scaling of the electricity system, which were important variables impacting on innovation (see section 11.1.4). These findings emphasize that the partial analysis that we executed highlighted only part of the explanatory variables in the whole array of explanatory variables, as is inherent in any partial analysis (see also Groenewegen and Vromen, 1996 and section 2.6).

The interviews contributed to a thorough understanding of the variables and relationships that are important in modernization. The survey resulted in a quantitative assessment of these important variables in modernization. In our interviews we were able to endogenize the actor's preferences, whereas in the survey we considered the preferences as given, or exogenous (section 8.2). According to Bowles (1998) there is ample evidence that endogenizing these preferences enhances our understanding of reality which subsequently would allow for more effective policy making. Although this perspective resembles reality better than the perspective with the preference element exogenized, it makes analysis of innovation less rigid. By using a historical analysis we incorporate the motivation for innovation, which leads to a large set of interconnected contextual factors and consequently to analyzing a sociological 'zoo'. However, this could provide us with a better understanding of how the government should act with regard to innovation as it would bring to light more intricate relationships of innovation than a more rigid and quantitative approach would.

12.1.3 Comparing perspectives

Both the logic in the alignment perspective and logic in the innovation system perspective use the layered approach. However, the logic of the different analytical perspectives cover different parts of reality. Whereas the alignment perspective focuses on the institutions that are relevant for the safeguarding of critical functions, the innovation system perspective highlights the institutions that impact on innovation. An example is the shift to a hybrid system in the alignment perspective (see Table 13) and the period since liberalization in the innovation system perspective (see Table 14). This example demonstrates that due to the different analytical perspectives, their logics might also differ considerably despite a large chronological overlap.

As addressed in section 2.6, we do not consider the innovation system theory or the alignment theory as more adequate than the other (theoretical monism). We rather consider the perspectives to focus on different parts of the issues or phenomena in the study (theoretical pluralism). Innovation in the electricity system can, for example, be an important exogenous variable in the analytical framework of alignment. This innovation can drive the misalignment in the system, that subsequently needs to be solved by modernization of the system, or more specifically, by a new innovation to restore alignment. An example is the innovation of AC technology, which had an impact on the electricity system since a new essential function of (load) balancing was introduced. This essential function had to be safeguarded in order to maintain a well performing system. Consequently, this potential misalignment could be regarded as a driver to a series of innovations, such as innovative controls and engines to automatically keep the system in balance. This example, thus, shows how both analytical frameworks cover specific important and complementary variables in the modernization of electricity networks. In conjunction the two perspectives yield a better understanding in the modernization phenomena than any single perspective would.

12.2 Practical implications

In this section we elaborate on the practical implications for policy makers of both analytical perspectives of the alignment and the innovation system.

12.2.1 Alignment perspective

The institutional layers in the alignment framework made it possible to find a logic between the institutional layers and to structure the institutional coordination mechanisms. We learned, for example, that the sector has been at a certain distance from the national government with as a most remarkable example the prominent role of the provinces instead of the national government in electrifying the Netherlands in the 1910s-1930s. Although we observed that the sector at certain instances is able to solve alignment problems itself (self organization), e.g. installation of phase shifters to avoid unwanted and sudden electricity currents from abroad, we also observed instances were the national government stepped in to restore alignment, e.g. with the Obstruction Act and more recently with the National Coordination Regulation. This indicates that per situation it should be determined at which institutional level any misalignment should be coped with. In other words, the context of the specific alignment issue is of utmost importance in determining the appropriate institutional or technical measure.

Whereas many economists and policy makers tend to focus mainly on the market mechanism as an instrument to enhance efficiency and economic welfare and not considering the specificities of the technology in their policy making effort (Jonker, 2009), many engineers are mainly concerned with the technical system control therewith ignoring any economic or institutional aspect (Künneke and Finger, 2007). The alignment perspective, however, focuses on both the technical and institutional aspects that are involved in modernization simultaneously. Emphasis is also on the critical functions of the system that have to be safeguarded (see also sections 4.2.1, 5.2.5 and 6.2.2). A number of current challenges that relate to the alignment of institutions and technology have been addressed in the previous chapters. In general we claim that such an alignment perspective leads to a better understanding of the alignment of institutions and technology in modernization which might result in anticipation of unwanted and misaligned situations. Some of the previously discussed illustrations with regard to DG and interconnections are examples of misalignment which led to unexpected and undesired situations. In this sense, the alignment perspective contributes to detect potential performance problems and to tackle these problems, which would contribute to an enhanced reliability of the system.

Examples that are still relevant nowadays are the large scale penetration of distributed generation resulting in issues as power quality, the stability of the network and balancing problems (discussed in section 7.2.1). It would be recommended to improve the coordination with regard to the location of DG facilities, for example, by providing incentives to have DG at suitable locations. However, we acknowledge that such coordination can encounter practical problems as the location can sometimes be fully dependent on the availability of the input for DG. For example, owners of greenhouses would typically install their CHP unit close to the greenhouse, which implies that the freedom of choice of location is restricted or path dependent (discussed in section 2.3 and 7.2.1). Other coordination recommendations relate to the timely announcement of electricity production of the system operator to contribute to a well balanced system. Other implications of DG were the increased capacity utilization of the network, which led to transport restrictions (section 7.2.2). Recommendations would be to better coordinate the installation of DG facilities with the expansion and reinforcement of the network. This could be either done by improving the procedure for prognosis of the transport needs for example through mandatory early indication of plans regarding new generation capacity. Another possibility would be to stimulate that DG facilities are located at suitable locations as discussed above. Another issue discussed previously is the typical shorter life time of DG assets compared to the network assets, which might lead to unused networks after the DG has been decommissioned and not renewed (section 7.2.2). Recommendations to cope with these issues are, for example, contracts between the energy company and the network company to keep a generation facility at a certain location for the life time of a dedicated network or the contribution of the DG owner in the total costs of these network assets.

Next to the small scale generation facilities we encountered issues related to large scale generation and the increasing interconnection of the networks leading to unwanted current flows (section 7.2.2). This can be coped with in a technical and in an institutional manner. Although in the case of the German wind mills the technical option was chosen, we would also suggest investigating a better institutional coordination in line with the technical scope to avoid such issues in the future. Possibly this would encounter some resistance as it might imply that national responsibilities would partly be allocated at a supranational coordination body. From the establishment of the EPZ and the SEP we have learned that the vested interests that are involved may hinder such institutional change considerably (section 6.1.2).

We previously elaborated on important general alignment issues that relate to the institutional unbundling of the electricity sector (section 7.1). Next to specifics of real time operations we focused on the lack of central planning with regard to production facilities and transport capacity and the current challenges that result from that. Although the system is institutionally decentral, the system is technically still very centralized. According to Kunneke (2008) the technological paradigm with a centralized approach that relies on centralized planning, control, and operations still holds at present. He stresses that the discrepancy between institutions and technological scope (or practice) possibly results in important problematic performance issues within the electricity sector. We argue along the same line that the institutional change of liberalization might only be sustainable if the technical integrated system is changing to a more decentralized (or decomposed) system. This shift to a decentralized system is, however, contradictory to the traditional paradigm in the electricity sector.

12.2.2 Innovation system perspective

The application of the innovation system perspective has resulted in an inventory of important variables impacting on innovation. Furthermore, the descriptions of the qualitative part provided us with an enhanced understanding of the variables in modernization prior to and since liberalization. Examples of prominent variables that impact on innovation are the authority within an organization that can promote innovative activity, for example the CEO of the company. Other variables are the culture of reliability, the share of engineers and the R&D facilities. In general we found that variables such as the culture of conservatism, the current tendering rules, the incentives for the shareholders and current regulation and tendering rules do not drive radical innovation (see also Biesboer, 2009). Regulation is very much focused on cost efficiency and quality and tendering is often based on costs only. We also found that to cover the risks that are accompanied with innovations more often than before extensive contractual arrangements between the technology supplier and the network company are used. With these contractual arrangements there is a tendency for technology suppliers to only provide conventional and proven technologies. If we want to increase the innovation activity of the sector we should focus on these important variables impacting on innovation. Policy makers and innovation managers in companies can construct innovation policies based on the key variables in the process of innovation. When constructing policy recommendations one should be aware that variables might work in combination with other variables and that intricate relations exist.[2]

From the logic of the institutional layers we learned that the central government does not steer the innovation as market parties are intrinsically, in their culture and actor organization, tending towards innovation. In other words, the logic is based on self organization with regard to innovation although among policy makers there is a persistent line of thinking with regard to central planning and design. The logic, however, shows that instead of central planning and design the central government should facilitate the self regulation with regard to innovation and allow market parties to find the most appropriate technology. In other words, it is not the end results which should be dictated by government policies, but the process of innovation that should be facilitated by government policies. This is in line with the evolutionary approach (section 2.4.3), which argues that transitions are not to be designed or managed but merely emerge from a certain set of (contextual) variables. The government should be able to intervene in cases that market parties cannot fulfil their duties with regard to innovation. For example, in order to allow for more radical innovations we suggest that the central government might opt for a more prominent role as current innovations tend to be more incremental.

This brings us to another more fundamental question that should first be answered: do we want to stimulate incremental or radical change of the system? Although (radical) innovation is sometimes assumed to be the ultimate objective, we believe that a more nuanced view is appropriate. We suggest that radical change of the system is, for example, needed if we want to accommodate more DG and if we want to arrive at a smart grid (see also section 2.4.1). The next question is then whether the demand pull for such radical change is large enough for the electricity sector, i.e. the market, to step in with innovations of network technology. Or oppositely, the sector with its current innovative activity could also be hampering the radical change of the system. The answer to this question should contribute to formulating a vision with regard to whether and how the government should direct its policies towards facilitating (instead of steering) this transition, e.g. by coordination to accommodate the radical change of the large technical electricity system. This can, for example, be done by incorporating a budget for innovation, for example directed at DG and smart grids, in the network tariffs, e.g. based on a percentage of the total turnover of the network company.[3] In this way the risks for the innovative technology can be allocated to all connected users.

Considering the above, there might be a need to accompany the institutional change to safeguard a well aligned system. This is also acknowledged by Kunneke (2008) who argues that in order to achieve a successful liberalized electricity sector there should be incentives to stimulate these technologies that allow for the development of a substantially decentralized electricity system. This suggestion combines both our analytical perspectives of alignment and the innovation system. An example of stimulating innovation in order to reach a decentralized system while safeguarding the alignment in the system is observed in the UK. Ofgem, the UK electricity and gas markets regulator, has developed so-called local control zones (or registered power zones). In these control zones the distributed generation facilities are provided favourable conditions for bounded experiments, therewith not jeopardizing the quality and supply of electricity to consumers. This is a means for actors to familiarize themselves with the implications of innovative technology (with regard to DG) and pursue innovation projects with higher risk profiles. This might result in technical, economic and institutional learning and in a potential cost reduction. (Shackley and Green, 2007). Another recommendation to broaden this regulation can be found in the Innovation Funding Incentive (IFI) as proposed by Ofgem. The IFI is an incentive that is particularly aimed at innovation that would lead to more cost efficient ways of integrating DG (OFGEM, 2003). This incentive applies more to the laboratory or field experiments while the registered power zones typically apply to demonstration projects.[4]

12.3 Suggestions for future research

By identifying the important variables in the modernization of the electricity networks in the Netherlands from two analytical perspectives we opened up new opportunities for further research. In the following, we suggest pathways for new research for both analytical perspectives. We end this section with a suggestion to combine these perspectives in one analytical framework.

12.3.1 Alignment perspective

The application of the alignment framework to the historical cases should be qualified as explorative research resulting in identification of important variables and relationships (section 11.1) in modernization. A suggestion for further research is to systemically test the generated hypotheses, i.e. the identified relationships as discussed in section 11.1 and assess the relationships of the different concepts within the conceptual framework of alignment and to further delineate hypotheses based on the findings from our research. The hypotheses could be validated or tested by applying them to additional historical analysis in the electricity sector. Further research on the hypotheses would also allow for further exploring the research field by posing additional questions such as: is modernization more often a result of alignment, or does alignment more often lead to modernization and what were the specific criteria to choose certain solutions to a (foreseen) misalignment?

We extended the conceptual framework of coherence by including not only the technical performance but also the economic performance and the public values performance in our model of alignment. A next step could be to further formalize the trade offs between these different performance categories into the existing conceptual model of alignment. On the one hand, this would enhance the understanding of the drivers in the process of modernization and alignment, as it would better describe the impact of alignment on these performance variables. On the other hand, changes in the demand of these performance categories, for example, a changing attitude with regard to the economic performance might have an influence on the criticality of certain functions. This might subsequently lead to a need for institutional or technical adaptation in order to fulfil this changed need.

Our empirical study demonstrated that the standard sequence is not always hold in which equilibrium is followed by a disequilibrium and than is followed by an equilibrium again. This sequence depends on the kinds of change to the system, either institutional or technical, and the conditions of the system (addressed in section 11.1). A suggestion for further research would be to build on these findings and further explore the conditions that influence institutional and technical change.

In our research we framed history along four main modernization processes (section 8.4): (1) the shift from DC to AC, (2) the electrification of the Netherlands, (3) the reinforcement and interconnection of the network and (4) the shift to a hybrid system. A suggestion for further research is to focus on other modernization processes beside the four main modernization processes that we addressed. Examples of possibly interesting modernization processes are the shift from above ground conductors to underground cables, the shift from oil pressured cables to XLPE cables, from mechanical relays to electronic relays. It would be interesting to determine to what extent the alignment framework is applicable to these cases for a more thorough understanding of these modernization processes. It might serve as a validation of the relationships as identified in this research or as a means to identify new relationships.

Another suggestion for further research is to frame history along the geographical enlargement of the electricity system, from local networks, to provincial networks, to national networks and finally to international networks. It would be interesting to further explore potential patterns in this process of system enlargement building on the identified patterns as addressed in section 11.1.4 as this would possibly reveal more commonalities among these system expansions.

In this research we focused on the Dutch situation with its typical Dutch features that determine the critical functions. Some general patterns of the shift to AC, the electrification and liberalization might be common among many countries. However, the specific way that the technical functions are handled may differ among countries. Another suggestion for further research is thus the application of the framework to other countries. This would also allow for a comparison between different countries, which could reveal national drivers for institutional and technological change in the electricity sector. As we have seen that the leading role of the provinces in the electrification as occurred in the Netherlands was more the exception than the rule, other interesting differences might be identified. A more recent example relates to the government policy in South Korea which is strongly directed at smart grids. This differs considerably from the Dutch situation in which individual network companies work towards smart grids and the role of the central government is more limited. The operationalization of the critical functions is sector specific. The same holds for the application of the conceptual framework. As shown in e.g. Finger and Künneke (2007) the alignment framework can be applied to other network industries beside the electricity industry. This would allow for identifying the differences and commonalities among modernization processes of network industries, which would show the applicability and robustness of the conceptual framework.

12.3.2 Innovation system perspective

The innovation system perspective highlighted a number of important variables impacting on innovation. Some variables are general in such a way that they apply to other countries besides the Netherlands. An example is the pioneering and engineering culture prior to liberalization and the more professional culture since liberalization. Other variables that are probably more country specific relate to the national regulations. Further research in that direction would allow for identifying the country specific and the general variables impacting on modernization from an innovation system perspective and it would enable comparison of the innovation systems.

In our research we conceptualized innovation as a process, but we did not give explicit attention to the sub processes such as invention, testing, demonstration in which the process of innovation can be subdivided. The identification of the specific variables impacting on these sub processes would allow for identification of more specific variables, which would provide input for more tailor made and therewith more effective policy recommendations.

This research showed that current innovations tend to be more incremental whereas prior to liberalization it tended to be more radical in nature. in order to make more thorough recommendations further research might be directed more in that direction with a survey directed at radical and incremental innovation as well as other types of innovations such as cost reducing and process innovations. A usual next step in innovation studies would be a further quantitative assessment by a regression analysis to determine which variables work well together in contributing to innovation. This would disentangle even more the complexity of the innovation subject. We question, however, the added value of such a regression analysis as reality is perhaps too complex to be boiled down to a set of individual or combined factors impacting on innovation. Furthermore, innovation is more of an emerging nature than that it can be designed with a set of institutions. Transitions and innovations are not designed, but only to be facilitated. Further research by a regression analysis would then not contribute to better policy recommendations, but would only indicate where further research should be based on. Possibly factor analysis[5] would be a way to combine variables and to assess their impact on innovation. The question is whether the sample size for such a sector analysis would be large enough to justify such an approach. Additionally, the question should be which further research step would add value with the least effort. Perhaps conducting additional interviews would suffice to gain a deeper understanding and a better idea of how variables work in combination in their impact on innovation.

As explained in section 12.1.2, the analytical perspective only highlights one part of the complexity. In our innovation system perspective, for example, only institutional variables were taken into account as the exogenous variables. Despite the fact that in our research we captured the relevant variables affecting innovation from our perspective, we encountered other important explanatory variables such as the growing demand and the expanding network. For further research we could add these variables to the innovation system in order to capture the most relevant explanatory variables. Technical variables could, for example, be added to gain more of an LTS perspective, incorporating both technical and social and organizational variables. This would be a step in the direction of formulation of a theory in which the alignment perspective and the innovation system perspective would be integrated. Previous work by Finger and Künneke (2007), for example, mentioned the possibility of dynamic efficiency in the conceptual framework of coherence. The theory of coherence (section 2.4.4) could in a further study be expanded with a dynamic systemic setting incorporating innovation in the framework as an endogenous variable, for example by considering innovation as an essential function in the coherence framework. We could, furthermore, divide this critical function into a number of categories following Hekkert et al. (2007) who distinguises seven functions in a technology specific innovation system (TSIS): (1) entrepreneurial activities, (2) knowledge development (learning), (3) knowledge diffusion through networks, (4) guidance of the search, (5) market formation, (6) resources mobilisation, and (7) support from advocacy coalitions. Incorporating these functions in the coherence framework would shed a whole new light on the modernization process from the innovation perspective. A more integrated approach given the complementarity of both perspectives would allow for identification of the interrelations of variables in both analytical frameworks such as the innovation system that stimulates an innovation that subsequently impacts the alignment of a system. It would, furthermore, allow for identification of the relation of the misalignment as a pull for innovations to solve this misalignment.

Notes on Chapter 12

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[1] See section 1.5 and 3.1 for an elaboration of the concept of hypothesis.

[2] This would e.g. hold for constructing policies to accommodate DG or to arrive at smart grids.

[3] Ideas for providing this is by raising the value for the Weighed Average Cost of Capital (WACC) in determining the tariff (see Reactie Tennet op consultatiedocument Innovatie (13 November 2009)) or by adjusting the x-factor in the tariff with an innovation component (see Reactie Liander op consultatiedocument Innovatie (13 November 2009)).

[4] Although we are aware that these incentives are subject to criticism and continuous improvement. See e.g. the Open Letter Consultation on the Innovation Funding Incentive and Registered Power Zone Schemes for Distribution Network Operators at www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=4&refer=NETWORKS/TECHN/NETWRKSUPP/INNOVAT

[5] Factor analysis is a collection of methods used to examine how underlying constructs infuence the responses on a number of measured variables. [..] Factor analyses are performed by examining the pattern of correlations (or covariances) between the observed measures. Measures that are highly correlated (either positively or negatively) are likely infuenced by the same factors, while those that are relatively uncorrelated are likely infuenced by different factors. (DeCoster, 1998: 1).

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Appendices

A Ancillary services

Ancillary services become necessary as networks become more interlinked and interdependence between network elements is arising. Examples of this are influences in voltage and control. These system variables should be taken care of in ancillary services to cope with these issues. What is considered an ancillary service in the electricity system differs per country (EURELECTRIC, 2004). Also, the definitions differ among scholars. The US Federal Energy Regulatory Commission (FERC, 1996) considers ancillary services as the basic components needed for open access operation of electric power transmission systems. Outhred (2001) considers ancillary services as a set of activities undertaken by generators, consumers and network service providers and coordinated by the system operator that have the following objectives:

> Implement the outcomes of commercial transactions, to the extent that these lie within acceptable operating boundaries. That is, ensure that electrical energy production and consumption by participants match the quantities specified by the outcomes of spot markets.
> Maintain availability and quality of supply at levels sufficient to validate the assumption of commodity-like behavior in the main commercial markets. This can be achieved by keeping the physical behavior of the electricity industry within acceptable operating boundaries defined by planning studies in conjunction with operator experience. (p. 2)

According to EURELECTRIC (2004: 9)), '[a]ncillary services are all services required by the transmission or distribution system operator to enable them to maintain the integrity and stability of the transmission or distribution system as well as the power quality.' Stoft (2002) states that '[u]sually ancillary services are defined by how they are provided rather than by the service rendered. Furthermore, he lists 'economic dispatch' and 'financial trade enforcement' as ancillary services. These aspects are seldom mentioned in other literature we encountered. We refer to the Appendix for an inventory of what are considered ancillary services by some scholars and TSOs. EURELECTRIC (2004) held a European survey on differences and similarities in ancillary services in EU countries. They list the following functions that minimally be considered ancillary service and their definitions are as following (11):

- Frequency control (FC): Maintaining the frequency within the given margins by continuous modulation of active power.

- Primary Response: The automatic response to frequency changes released increasingly with time over a period of some seconds from the time of frequency.
- Secondary Response: The automatic response to frequency changes which takes over from the Primary Response and partially recovers system frequency.
- In certain cases, high frequency response can be separately defined:
- High Frequency Response: An automatic reduction in active power output in response to an increase in system frequency, released increasingly with time over the period 0 to some seconds from the time of the frequency increase.
- Voltage control (VC): Maintaining voltage through injecting or absorbing reactive power by means of synchronous or static compensation.
- Spinning reserve (SP): Increase or decrease in generation or reduction in consumption that can be provided at short notice, carried out by partially loaded generating units and interruptible customers.
- Standing reserve (ST): Increase in generation or reduction in consumption that can be provided by those generating units that are not synchronously on-line, or by interruptible customers.
- Black start capability (BS): The capability of a generating unit to start up without an external power supply, called on as a means of restoring supplies following a major failure on all or part of the network.
- Remote automatic generation control (RG): A means of regulating frequency by controlling the output through a centrally-based control system. It can mean operating the Secondary Response but also controlling a whole plant.
- Emergency control actions (EC): Maintenance and use of special equipment (e.g. power-system stabilisers and dynamic-braking resistors) to maintain a secure transmission system.
- Grid loss compensation (GL): Compensating the transmission system losses between the generators and the loads.

Although it is in many other countries, the latter service, grid loss compensation, is not considered an ancillary service in the Netherlands. Ancillary services do not cover all that is considered capacity management functions. Capacity management also refers to longer term aspects such as maintenance and building of new parts of the electricity network.

Long term aspects are not in most ancillary services definitions. However, the long term aspects are more related to the concept of modernization. In the following we observe longer term aspects of the system relevant function of capacity management.

Table 15 Attributes of Dutch ancillary services

	Frequency control	Voltage control	Spinning reserve	Standing reserve	Black start capacity
Considered AS	Yes	Yes	Yes	Yes	Yes
Mandatory	Yes, > 5 MW	No	No	Obligations to offer free reserve to TSO	No
Procurer AS	TSO	TSO distributors	TSO	TSO	TSO
Provider AS	generators	generators	generators	generators	generators
Procurement payment method	Obligation without payment	Negotiated contracts	Negotiated contracts	Open market bidding	Negotiated contracts
Cost determination	-	Open market	Open market	Open market	Open market
Price definition	-	regulated	regulated	regulated	regulated
Price recovered from	-	Generators customers	Generators customers	Generators customers	Generators customers
Mechanism for price recovery	-	uplift	Uplift; System imbalance cost	Uplift; System imbalance cost	uplift
Basis of selecting AS providers		Minimum dispatch cost; technical considerations	Minimum dispatch cost; technical considerations	Minimum dispatch cost; technical considerations	technical considerations

	Remote automatic generation control	Emergency control	Grid loss compensation	Economic dispatch	Financial trade enforcement
Considered AS	Yes	Yes	No	No	No
Mandatory	No	No	No		
Procurer AS	Obligations to bid free reserve to TSO	TSO	TSO distributors		
Provider AS	generators	generators	-		
Procurement payment method	-	Negotiated contracts	Open market		
Cost determination	Open market	Open market	Open market		
Price definition	-	regulated	regulated		
Price recovered from	-	Generators customers	Generators customers		
Mechanism for price recovery	Uplift; System imbalance cost	Uplift; System imbalance cost	uplift		
Basis of selecting AS providers		-	technical considerations	Minimum dispatch cost	

Source: EURELECTRIC, 2004

B Electricity use and installed capacity

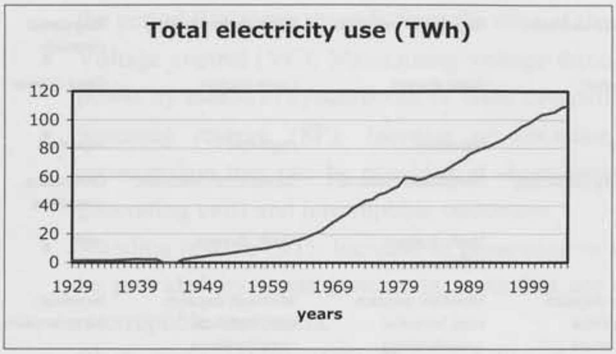

Figure 38 Total electricity use 1929-2005
Source: EnergieNed (2007c)

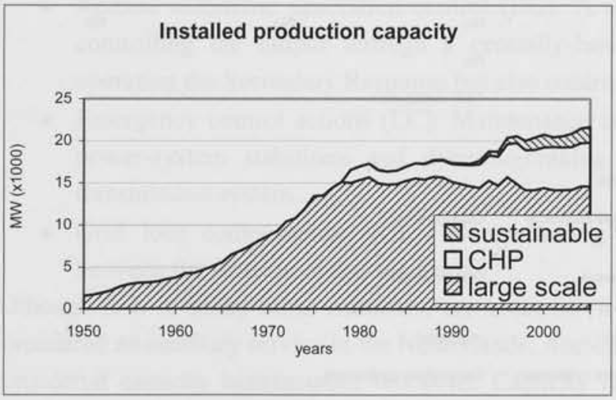

Figure 39 Installed production capacity 1950-2005
Source: EnergieNed (2007a)

C Questionnaire

Vragenlijst: het creëren van innovatieve netwerktechnologie

Deze vragenlijst heeft als doel om een goed beeld te krijgen van de factoren die een rol spelen bij het creëren van nieuwe/innovatieve technologie op gebied van elektriciteitsnetwerken. Deze vragenlijst is bedoeld voor personen die reeds voor 1998 in de elektriciteitssector werkzaam waren en dient individueel ingevuld te worden. Aangezien ik geïnteresseerd ben in uw perspectief zijn er dus geen foute antwoorden te geven. Uw antwoorden zullen vertrouwelijk worden behandeld. Het invullen van de vragenlijst zal ongeveer 10 minuten in beslag nemen.

Alvast hartelijk dank voor uw medewerking.

DEEL 1: VROEGER, een indruk van het innovatieproces VOOR 1998.

A. Wat is de naam van de organisatie en functie waar u voor het grootste deel werkzaam was voor 1998?

(Indien u niet voor 1998 in de sector werkzaam was verzoeken wij u te beginnen met Deel 2: TEGENWOORDIG, een indruk van het innovatieproces vanaf 1998 tot nu)

A1: Functie: ....

A2: Organisatie ....

(houd bij de beantwoording van de volgende vragen deze organisatie in gedachten)

LEES ONDERSTAANDE S.V.P. VOORDAT U AAN HET INVULLEN VAN DE VRAGENLIJST BEGINT:

Onder innovatie verstaan we een ontwerp/ontwikkeling van een netwerkcomponent of een netwerksysteem met

- een nieuwe interne structuur of
- een nieuw technisch werkingsprincipe of
- een nieuwe functionaliteit.

Een voorbeeld is de ontwikkeling van de XLPE kabels (in plaats van kabels met papieren isolatie), de ontwikkeling van intelligentie in de netten, de ontwikkeling van het elektronische relais (in plaats van mechanische relais).

We zijn specifiek op zoek naar nieuwe technologie van **netwerken/netwerkcomponenten** in Nederland. Innovatie op gebied van opwekking van elektriciteit valt hiermee dus buiten dit onderzoek.

De volgende vragen hebben betrekking op de creatie van netwerktechnologie voor 1998. Markeer s.v.p. uw antwoord door het aanvinken van een vakje per regel.

B. Waarden in uw organisatie in de periode voor 1998

Tot welke mate van innovatie op gebied van netwerktechnologie droegen de volgende *waarden* in deze organisatie (dus de organisatie waar u toen werkte) bij?

B	Waarde	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
B1	Cultuur van streven naar netwerkbetrouwbaarheid	1☐	2☐	3☐	4☐	5☐	☐
B2	Prestige van innovatie	1☐	2☐	3☐	4☐	5☐	☐
B3	Streven naar kostenefficiëntie	1☐	2☐	3☐	4☐	5☐	☐
B4	Cultuur van pionieren/hobbyisme	1☐	2☐	3☐	4☐	5☐	☐
B5	Cultuur van samenwerking in de sector	1☐	2☐	3☐	4☐	5☐	☐
B6	Lange termijn denken (in tegenstelling tot huidig korte termijn denken)	1☐	2☐	3☐	4☐	5☐	☐
B7	Conservatisme/behoudendheid	1☐	2☐	3☐	4☐	5☐	☐
B8	Andere waarden, nl...........................	1☐	2☐	3☐	4☐	5☐	☐

1

C. Eigendom, regulering en markt in de periode voor 1998

Tot welke mate van innovatie op gebied van netwerktechnologie droegen de volgende *factoren* in deze organisatie (dus de organisatie waar u toen werkte) bij?

C	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
C1	De rol van de grootste aandeelhouder(s) van uw organisatie (Rijk, provincie, gemeente, E-bedrijf of private partij)	1❑	2❑	3❑	4❑	5❑	❑
C2	De regulering die op uw organisatie wordt uitgeoefend	1❑	2❑	3❑	4❑	5❑	❑
C3	De monopoliepositie van uw bedrijf in de sector	1❑	2❑	3❑	4❑	5❑	❑

D. Individuele projecten en samenwerkingsprojecten in de periode voor 1998

Tot welke mate van innovatie op gebied van netwerktechnologie droegen de volgende *factoren* in deze organisatie (dus de organisatie waar u toen werkte) bij?

D	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
D1	Individuele innovatieprojecten (zonder samenwerking met/door een andere partij)	1❑	2❑	3❑	4❑	5❑	❑
D2	Innovatieprojecten via de Meerjarige Collectieve Opdracht (COP)	1❑	2❑	3❑	4❑	5❑	❑
D3	Andere samenwerkingsverbanden (dus buiten de Meerjarige Collectieve Opdracht (COP))	1❑	2❑	3❑	4❑	5❑	❑

E. Innovatie over het algemeen in Nederland in de periode voor 1998

In welke mate was er sprake van creatie van nieuwe netwerktechnologie voor 1998...

E		Geen innovatie	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
E1	...in uw organisatie?	1❑	2❑	3❑	4❑	5❑	❑
E2	...in gemeentelijke energiebedrijven in het algemeen?	1❑	2❑	3❑	4❑	5❑	❑
E3	...in provinciale energiebedrijven in het algemeen?	1❑	2❑	3❑	4❑	5❑	❑
E4	... in het nationale energiebedrijf (SEP) in het algemeen	1❑	2❑	3❑	4❑	5❑	❑
E5	...in toeleveranciers van energiebedrijven?	1❑	2❑	3❑	4❑	5❑	❑
E6	...in de algehele E-sector?	1❑	2❑	3❑	4❑	5❑	❑

Als u verder nog opmerkingen, commentaar of suggesties heeft over dit deel kunt u deze hier beschrijven:

....

....

Hiermee eindigt het onderdeel met betrekking tot innovatieprocessen van **voor 1998.**

2

DEEL 2: TEGENWOORDIG, een indruk van het innovatieproces vanaf 1998 tot nu.

F0. Wat is de naam van de organisatie waar u voor het grootste deel werkte vanaf 1998?

F1: Functie: ....

F2: Organisatie ....

(houd bij de beantwoording van de volgende vragen deze organisatie in gedachten)

De volgende vragen hebben betrekking op de creatie van netwerktechnologie in de periode na 1998. Markeer s.v.p. uw antwoord door het aanvinken van een vakje per regel.

G. Waarden in uw organisatie vanaf 1998

In welke mate dragen de volgende *waarden* tegenwoordig in uw organisatie bij aan de innovatie op gebied van netwerktechnologie?

G	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
G1	Cultuur van streven naar netwerkbetrouwbaarheid	1☐	2☐	3☐	4☐	5☐	☐
G2	Prestige van innovatie	1☐	2☐	3☐	4☐	5☐	☐
G3	Streven naar kostenefficiëntie	1☐	2☐	3☐	4☐	5☐	☐
G4	Cultuur van pionieren en hobbyisme	1☐	2☐	3☐	4☐	5☐	☐
G5	Cultuur van samenwerking in de sector	1☐	2☐	3☐	4☐	5☐	☐
G6	Korte termijn denken (ipv vroegere lange termijn denken)	1☐	2☐	3☐	4☐	5☐	☐
G7	Conservatisme	1☐	2☐	3☐	4☐	5☐	☐
G8	Cultuur van concurrentie	1☐	2☐	3☐	4☐	5☐	☐
G9	Andere waarden, nl........................	1☐	2☐	3☐	4☐	5☐	☐

H. Eigendom, regulering, markt vanaf 1998

Tot welke mate van innovatie op gebied van netwerktechnologie dragen de volgende *factoren* vanaf 1998 in uw organisatie bij?

H	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
H1	De rol van grootste aandeelhouder van uw organisatie (nat. overheid, provincie, gemeente of private partij)	1☐	2☐	3☐	4☐	5☐	☐
H2	Competitieve sector (in vergelijking met vroeger)	1☐	2☐	3☐	4☐	5☐	☐
H3	Korte 'time to market' voor suppliers van netwerktechnologie	1☐	2☐	3☐	4☐	5☐	☐
H4	De x-tariefregulering van DTe	1☐	2☐	3☐	4☐	5☐	☐
H5	De gecombineerde x (tarief)- en q-(kwaliteits)regulering van DTe	1☐	2☐	3☐	4☐	5☐	☐
H6	De huidige 'verplichte EU-tendering'	1☐	2☐	3☐	4☐	5☐	☐

3

I. Individuele projecten of in samenwerkingsverband vanaf 1998

Tot welke mate van innovatie op gebied van netwerktechnologie dragen de volgende *factoren* vanaf 1998 in uw organisatie bij?

I	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
I1	Individuele innovatieprojecten (zonder samenwerking met/door een andere partij)	1❑	2❑	3❑	4❑	5❑	❑
I2	Innovatieprojecten via Hermes	1❑	2❑	3❑	4❑	5❑	❑
I3	Andere samenwerkingsverbanden (dus buiten Hermes)	1❑	2❑	3❑	4❑	5❑	❑

J. Innovatie over het algemeen in Nederland vanaf 1998

In welke mate is er sprake van creatie van nieuwe netwerktechnologie na 1998...

J	Factor	Geen innovatie	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
J1	...in uw organisatie?	1❑	2❑	3❑	4❑	5❑	❑
J2	...in distributiebedrijven in het algemeen	1❑	2❑	3❑	4❑	5❑	❑
J3	...in de transmissienetwerkbeheerder (TenneT) in het algemeen	1❑	2❑	3❑	4❑	5❑	❑
J4	...in toeleveranciers van energiebedrijven	1❑	2❑	3❑	4❑	5❑	❑

Als u verder nog opmerkingen, commentaar of suggesties heeft over dit deel kunt u deze hier beschrijven:

....

....

Hiermee eindigt het onderdeel met betrekking tot innovatieprocessen **vanaf 1998**.

DEEL 3: SUBSIDIEREGELINGEN

De volgende vragen betreffen factoren die mogelijk binnen uw bedrijf een rol spelen in het creëren van nieuwe netwerktechnologie. Markeer s.v.p. uw antwoord door het aanvinken van een vakje per regel.

K. Subsidieregelingen

Tot welke mate van innovatie op gebied van netwerktechnologie dragen de volgende *factoren* in uw organisatie bij?

K	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
K1	WBSO (Wet Bevordering Speur en Ontwikkelingswerk)	1❑	2❑	3❑	4❑	5❑	❑
K2	IOP EMVT (Innovatiegericht OnderzoeksProgramma, Elektromagnetische VermogensTechniek)	1❑	2❑	3❑	4❑	5❑	❑
K3	EOS (Energie Onderzoek Subsidie)	1❑	2❑	3❑	4❑	5❑	❑
K4	Andere regeling, nl................................	1❑	2❑	3❑	4❑	5❑	❑

DEEL 4: ALGEMENE FACTOREN BINNEN EEN ORGANISATIE

4

L. Algemene factoren die van invloed kunnen zijn. Het gaat er dus hierbij niet om of dit in uw organisatie momenteel aan de orde is, maar om de vraag wat voor invloed het zou hebben op de creatie van innovatieve technologie. Markeer s.v.p. uw antwoord door het aanvinken van een vakje per regel

Tot welke mate van innovatie op gebied van netwerktechnologie zouden de volgende factoren in uw organisatie bijdragen?

L.	Factor	Geen innovatie/ geen invloed	Geringe mate van innovatie	Matige mate van innovatie	Hoge mate van innovatie	Zeer hoge mate van innovatie	Weet niet
L1	Een aparte R&D afdeling	1❑	2❑	3❑	4❑	5❑	❑
L2	Een sterke marketing afdeling	1❑	2❑	3❑	4❑	5❑	❑
L3	Een hoog aandeel ingenieurs	1❑	2❑	3❑	4❑	5❑	❑
L4	Een CEO die ingenieur	1❑	2❑	3❑	4❑	5❑	❑
L5	Kleine omvang van de organisatie (sneller te testen/minder formele toestemming)?	1❑	2❑	3❑	4❑	5❑	❑
L6	Grote omvang van de organisatie (meer budget voor technologie-ontwikkeling)?	1❑	2❑	3❑	4❑	5❑	❑
L7	De korte termijn incentive structuur voor aandeelhouders	1❑	2❑	3❑	4❑	5❑	❑
L8	De korte termijn incentive structuur voor de CEO	1❑	2❑	3❑	4❑	5❑	❑
L9	Een gezaghebbende initiatiefnemer voor innovatie in de organisatie	1❑	2❑	3❑	4❑	5❑	❑
L10	De mogelijkheid om innovatie in het tarief te brengen (zogenaamde z-tarivering in UK)	1❑	2❑	3❑	4❑	5❑	❑

Als u verder nog opmerkingen, commentaar of suggesties heeft kunt u die hieronder of op de volgende pagina beschrijven:
....
....
....
....

Dit is het eind van de vragenlijst. Hartelijk dank voor uw medewerking!

5

D Codes of survey variables and data matrix

No	Code	Description
B1	A98 reliability	Culture of reliability
B2	A98 prestige	Prestige of innovation
B3	A98 cost eff	Culture of cost efficiency
B4	A98 pioneering	Culture of pioneering
B5	A98 collaboration	Collaborative culture among actors
B6	A98 long term	Culture of long term thinking
B7	A98 conservatism	Culture of conservatism
C1	A98 shareh	Shareholders' role in innovation process
C2	A98 regulation	Regulation on company
C3	A98 monopoly	Monopoly position of the company
D1	A98 individual	Individual innovation projects
D2	A98 COP	Innovation projects within the COP platform
D3	A98 other coll	Other collaborative innovation projects
E1	A98 org	innovativeness of the organization of the respondent
E2	A98 muni	innovativeness of the municipal energy company
E3	A98 prov	innovativeness of the provincial energy company
E4	A98 nat	innovativeness of the national energy company
E5	A98 supp	innovativeness of the supplier company
E6	A98 overall	innovativeness overall
G1	P98 reliability	Culture of reliability
G2	P98 prestige	Prestige of innovation
G3	P98 cost efficiency	Culture of cost efficiency
G4	P98 pioneering	Culture of pioneering
G5	P98 collaboration	Collaborative culture among actors
G6	P98 short term	Culture of short term thinking
G7	P98 conservatism	Culture of conservatism
G8	P98 competition	culture of competition
H1	P98 shareholder	Shareholders' role in the innovation process
H2	P98 competition	competitive sector
H3	P98 tt market	Time to market of products
H4	P98 x tariff	x -tariff regulation

H5	P98 x/q tariff	x and q - tariff regulation
H6	P98 tender	tendering directive
I1	P98 individual	Individual innovation projects
I2	P98 Hermes	Innovation projects within Hermes platform
I3	P98 other coll	Other collaborative innovation projects
J1	P98 org	innovativeness of the organization of the respondent
J2	P98 DSO	innovativeness of the municipal energy company
J3	P98 TSO	innovativeness of the provincial energy company
J4	P98 supp	innovativeness of the national energy company
K1	WBSO	WBSO subsidy scheme
K2	IOP	IOP subsidy scheme
K3	EMVT	EMVT subsidy scheme
L1	R&D	R&D department
L2	marketing	marketing department
L3	share eng	share of engineers
L4	CEO eng	engineer as CEO
L5	small scale	small scale organization
L6	big scale	big scale organization
L7	inc shareh	incentives shareholders
L8	inc CEO	incentives CEO
L9	authority	authority on innovation
L10	Z tariff	Z tariff incorporating innovation budget

no	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	D1	D2	D3	E1	E2	E3	E4
1	na	Trainee	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
2	na	Manager Bedrijfsbureau	4	2	4	3	4	3	1	1	1	1	2	4	2	3	2	3	3
3	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
4	DSO	Projectmanager Transport	4	4	4	4	4	4	3	3	4	3	4	3	3	4	3	3	3
5	SUP	Development specialist	4	3	3	4	4	3	2	1	2	2	4	1	4	4	3	4	3
6	DSO	Chef Technologie	5	4	2	4	4	4	2	3	2	4	3	4	4	4	3	4	3
7	SUP	Productieleider	5	4	3	3	4	4	4	3	2	3	4	2	3	4	2	3	2
8		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
9	SUP	Ontwerper	2	1	4	4	2	3	5	1	1	2	3	1	1	1	9	9	9
10	SUP	Business Unit Manager	5	4	3	4	5	5	2	4	1	1	4	2	2	3	2	3	2
11	OTH	Specialist	2	4	2	5	4	3	2	2	2	4	4	4	2	4	2	2	1
12	OTH	Onderzoeker	2	4	3	5	4	4	2	2	1	2	4	3	3	3	1	2	2
13	TSO	Staf	2	2	2	1	2	2	2	2	1	3	1	2	2	1	2	2	2
14	DSO	Senior Consultant	3	5	2	5	4	4	1	2	2	3	na	na	na	na	na	na	na
15	DSO	Voorbereider	2	3	2	2	2	3	1	2	2	2	3	2	2	2	2	2	2
16	DSO	Netwerkstrateeg assetmana	4	3	2	4	3	3	2	3	3	2	4	2	2	3	3	3	3
17	DSO	R&D Manager	4	3	3	5	3	2	2	1	2	2	5	3	5	4	2	3	2
18	DSO	Diverse functies	4	2	4	2	3	4	4	1	1	2	2	3	2	4	2	3	3
19	DSO	Stafmedewerker	5	4	3	4	2	4	3	2	3	3	4	4	4	4	2	4	2
20	DSO	Hoofd Transport	4	2	4	2	5	5	2	1	1	4	4	3	2	3	2	3	2
21	SUP	Account Manager voor de N	2	1	4	2	3	4	1	4	1	1	4	1	1	3	2	3	4
22	DSO	In 22 jaar daar vele functies	4	2	3	2	4	3	1	2	1	3	3	4	3	2	2	3	3
23	TSO	Hoofd prognoses	3	2	3	4	3	5	2	3	4	4	3	4	3	3	2	2	3
24	DSO	Specialist planning infrastru	5	4	5	5	4	5	4	4	4	4	4	5	4	4	9	9	4
25	DSO	Hoofd Stations	4	3	4	4	4	4	3	2	2	2	3	4	3	4	3	3	3
26	SUP	Business Consultant	9	4	5	2	2	2	1	1	1	1	9	1	9	1	2	3	4
27	TSO	manager procesautomatiseri	2	2	2	1	1	1	1	1	1	1	1	2	2	2	1	1	2
28	DSO	Medewerker energievoorzie	2	1	1	2	2	1	2	9	1	9	3	3	3	2	2	9	9
29	DSO	projectleider/engineer	4	3	4	3	4	3	3	2	2	2	3	2	1	3	3	3	3
30	DSO	Manager E-Transport	4	3	4	3	4	5	2	1	1	4	3	4	3	4	3	3	4
31	DSO	consultant	3	3	4	1	3	3	2	1	1	1	2	3	3	2	2	2	9
32	SUP	QA-Manager	3	3	4	2	3	3	3	2	1	3	3	3	3	2	3	3	4
33	DSO	Projectengineer	1	2	2	4	4	1	2	1	1	1	4	4	4	2	2	2	2
34	DSO	Hoofd netbeheer	4	4	4	3	4	4	3	2	2	2	3	4	4	4	3	3	2
35	DSO	Hdviseur	3	4	5	3	5	4	3	4	2	3	3	4	4	3	3	2	2
36		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
37	DSO	HS-deskundige	5	2	3	4	4	3	2	1	1	3	4	3	2	4	2	3	2
38	TSO	Senior engineer	4	3	3	3	4	4	3	2	2	4	4	3	2	4	2	3	4
39	DSO	Hoofd studiebureau	3	1	1	1	3	3	9	1	1	1	1	3	1	na	na	na	na
40	DSO	Projectingenieur	2	9	4	4	4	4	4	1	1	4	3	3	2	2	2	4	3
41	DSO	Hoofd netplanning	3	4	3	4	4	4	3	1	1	3	5	3	3	4	4	3	2
42	DSO	Manager bedrijfsbureau	5	4	3	3	4	4	3	1	1	4	4	4	3	4	2	4	3
43		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
44	DSO	Monteur tot hoofdopzichte	2	2	2	2	2	2	2	2	3	2	3	3	3	3	3	9	9
45	DSO	Projectleider	3	4	3	4	3	3	2	2	2	2	4	3	3	3	4	3	3
46	DSO	Rayoninspecteur	5	1	1	3	5	4	9	1	1	2	2	4	9	2	2	3	9
47	DSO	Directeur	4	2	4	3	4	5	2	2	2	3	4	4	3	3	3	3	3
48	DSO	Chef Stafbueau/Expert MS/	4	3	3	3	4	4	2	2	2	4	5	3	3	3	3	3	4

no	E5	E6	F1	F2	G1	G2	G3	G4	G5	G6	G7	G8	H1	H2	H3	H4	H5	H6
1	na	na	DSO	Beleidsadviseur netwontw	5	4	5	1	3	2	2	2	3	2	na	1	4	1
2	4	3	DSO	Manager Asset Managem	4	2	4	2	3	2	1	2	1	1	2	1	1	1
3	na	na	SUP	Innovation manager	2	5	2	5	4	1	2	2	na	2	1	2	3	3
4	3	3	DSO	Asset manager	3	2	2	2	2	2	2	2	2	2	2	3	na	3
5	4	3	SUP	Head development MV	4	4	4	2	3	3	3	4	4	4	3	2	2	3
6	3	4	DSO	Hoofd operatie AM	3	3	4	3	2	2	2	3	3	3	2	3	3	2
7	3	3	SUP	Systeem Engineer	3	3	5	2	3	4	3	3	5	3	4	9	9	3
8	na	na		Innovation Manager	3	5	4	5	5	1	1	2	3	2	2	3	4	1
9	2	9	SUP	Technisch Specialist	2	3	4	3	9	1	2	4	2	2	9	9	9	9
10	3	3	SUP	Business Unit Manager	5	5	4	4	4	4	3	5	3	5	5	2	2	4
11	3	3	SUP	Directeur	4	4	3	4	4	3	2	4	4	4	4	3	3	4
12	3	2	OTH	consultant	4	2	5	2	1	4	2	4	1	3	4	3	4	9
13	3	3	TSO	Staf	2	4	3	4	3	1	3	1	3	2	1	2	1	1
14	na	na		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
15	3	3	DSO	Manager Netbeheer	5	5	4	2	3	4	4	4	4	4	4	4	4	9
16	3	3	DSO	Netwerkstrateeg	3	3	2	3	3	3	2	2	2	3	3	3	3	3
17	3	3	DSO	Manager R&D	4	5	3	5	2	2	2	3	2	2	2	2	2	2
18	3	3	DSO	Project manager	4	2	4	2	3	2	3	3	2	3	3	3	3	2
19	4	2	DSO	Beleidsadviseur	4	4	5	2	4	4	2	4	2	2	3	3	3	3
20	4	3	DSO	Assetmanager	4	5	4	5	2	4	2	4	1	4	4	2	4	2
21	3	3	SUP	Account Manager voor de	4	2	4	4	3	1	1	4	1	4	3	9	9	1
22	4	3	DSO	Directeur	3	2	3	2	2	2	1	3	2	3	3	2	2	1
23	4	3	TSO	project adviseur	2	3	3	4	3	3	2	2	2	2	3	2	2	2
24	4	4	DSO	Senior Specialist	4	3	4	3	3	4	3	3	3	3	4	4	4	4
25	4	3	DSO	Manager Technologie & In	3	2	3	3	2	2	2	2	2	2	3	2	2	2
26	3	3	SUP	Business Consultant	3	3	5	2	2	3	2	3	2	3	9	2	4	2
27	2	1	TSO	Programmamanager Innov	2	4	3	1	3	2	1	1	3	1	1	2	2	2
28	3	9	DSO	Sr. Specialist Asset Mana	3	3	4	2	4	3	2	4	9	3	2	4	4	9
29	4	3	SUP	directeur-eigenaar	4	3	3	1	1	2	2	3	2	2	3	1	1	1
30	3	4	DSO	Manager E-Transport	2	2	2	2	2	2	3	2	2	2	3	1	2	2
31	2	2	DSO	consultant	2	3	5	1	3	1	1	2	1	2	3	2	2	1
32	3	3	SUP	Area Manager	3	3	5	2	3	4	3	2	4	2	4	1	1	3
33	3	2	SUP	Directeur	4	2	4	1	1	1	1	1	1	4	4	1	1	2
34	4	3	DSO	Asset manager	4	4	3	2	3	2	2	4	2	4	3	3	3	3
35	4	2	DSO	coördinator R&D	3	4	5	1	3	4	4	4	5	4	3	4	3	2
36	na	na		Risico Analist	4	3	5	3	4	3	2	4	2	2	4	4	4	3
37	4	3	DSO	Assetmanager	4	4	5	4	2	4	1	4	2	3	9	4	5	2
38	3	3	TSO	Netwerk strateeg	4	3	3	2	2	2	3	3	3	3	2	3	2	2
39	na	na		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
40	3	3	DSO	Specialist Asset Managem	5	3	5	2	4	2	2	2	3	4	3	5	5	4
41	4	3	DSO	Manager projecten Assetr	5	3	5	3	4	2	1	1	3	5	4	5	4	3
42	4	3	DSO	Manager AM	4	2	3	2	3	4	2	2	2	2	2	1	2	2
43	na	na		Manager ingenieursbureau	3	2	3	4	4	3	3	3	3	4	5	3	3	3
44	4	9	DSO	Hfd opzichter tot TL	3	3	4	3	2	3	5	2	2	3	3	3	4	2
45	4	3	DSO	Projectleider	3	4	4	3	3	3	3	4	3	4	4	4	4	3
46	3	3	DSO	Hoofd Storingen & Onderh	3	2	4	1	2	2	9	9	9	9	9	9	3	9
47	3	3	OTH	Directeur	3	4	4	2	2	2	2	3	1	4	2	3	3	2
48	3	3	DSO	Medewerker Innovatie/Exp	3	2	2	1	2	4	5	2	na	na	na	na	na	na

no	I1	I2	I3	J1	J2	J3	J4	K1	K2	K3	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
1	4	2	3	4	3	2	3	5	3	3	4	2	3	5	3	4	1	1	5	5
2	1	2	3	2	1,5	2	3	2	2	2	3	1	3	3	3	4	1	1	4	4
3	4	na	3	2	2	na	2	3	3	3	5	4	5	4	4	3	2	2	5	9
4	2	3	2	2	2	2	2	2	2	3	4	3	3	4	2	4	4	4	4	4
5	4	2	4	3	3	3	3	5	4	1	4	4	4	3	4	3	1	2	5	4
6	4	3	4	3	4	2	3	3	4	3	5	3	4	5	4	4	3	3	4	4
7	4	2	3	3	2	2	2	9	9	9	5	2	5	5	5	3	2	2	5	9
8	4	9	5	2	4	9	3	1	3	9	4	4	5	4	5	3	1	1	5	9
9	2	9	9	2	9	9	9	3	2	9	3	3	5	4	9	9	1	1	5	9
10	4	2	4	4	2	2	4	3	3	2	3	4	4	3	4	4	4	5	5	3
11	4	3	4	3	3	1	3	1	3	1	4	2	4	4	4	3	1	2	5	9
12	4	2	3	3	2	2	3	2	2	3	3	2	4	4	3	2	1	1	5	4
13	4	2	2	3	3	3	2	2	2	2	4	2	4	3	2	4	2	3	4	4
14	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
15	4	3	3	4	3	3	3	1	1	1	3	2	2	2	3	1	3	9	4	1
16	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3	3
17	5	2	4	5	2	2	3	3	4	3	5	3	5	4	5	2	2	2	4	2
18	4	3	4	3	3	2	4	2	3	3	3	2	3	2	3	4	3	3	5	3
19	4	4	4	4	3	3	4	3	3	3	2	2	4	4	3	4	3	3	4	9
20	4	2	2	4	3	3	4	1	2	2	3	2	4	4	3	4	2	2	4	2
21	3	9	4	3	3	4	4	9	4	9	4	3	5	5	4	3	9	3	4	9
22	2	9	9	2	2	3	3	9	9	9	4	3	4	4	2	3	2	2	3	3
23	4	4	3	3	3	3	4	9	9	9	5	3	5	4	3	4	2	2	5	5
24	3	4	3	3	3	4	3	9	9	4	5	3	4	4	3	4	4	4	4	5
25	3	3	3	3	3	3	3	2	2	2	4	3	4	4	3	3	2	2	4	3
26	3	9	9	2	2	3	3	9	9	9	3	4	4	4	4	3	9	9	5	4
27	3	3	3	3	3	3	3	2	3	3	2	1	3	3	2	2	2	2	4	4
28	3	4	4	3	3	9	4	9	9	9	5	2	4	4	4	2	5	4	4	3
29	2	1	1	2	2	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1
30	2	2	2	2	2	2	2	3	3	3	4	2	4	3	2	3	1	1	3	3
31	2	9	9	2	2	9	3	9	9	9	3	1	4	5	4	1	9	9	4	1
32	4	1	2	2	4	4	3	3	3	3	4	3	4	5	2	4	2	2	4	1
33	3	9	9	1	2	2	3	1	1	1	1	1	3	1	3	1	1	1	1	1
34	4	9	9	4	3	2	3	9	9	9	4	2	3	4	2	4	3	3	5	4
35	2	3	4	2	3	9	3	2	3	2	3	3	4	4	3	3	4	4	5	4
36	4	3	4	3	3	3	3	9	9	4	4	3	4	4	3	3	3	3	5	4
37	4	3	4	4	3	2	3	9	9	9	3	4	3	2	3	4	2	4	4	9
38	4	2	3	4	3	4	3	2	3	3	3	2	3	4	3	3	2	3	4	4
39	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
40	3	2	4	3	3	9	4	9	4	9	4	2	2	3	2	4	2	3	4	5
41	5	4	5	5	4	3	3	1	3	3	5	3	4	4	3	4	3	3	5	4
42	2	3	4	3	3	3	3	2	2	2	3	2	4	4	3	4	3	3	4	4
43	4	9	4	3	3	3	3	9	9	9	5	3	5	3	5	3	3	3	5	5
44	3	9	9	2	3	9	3	2	3	3	3	3	2	2	3	3	2	2	2	2
45	4	3	3	4	3	3	4	9	9	9	4	3	3	4	4	3	2	3	4	4
46	9	9	9	3	3	9	3	9	9	9	9	2	4	2	3	2	9	9	4	9
47	4	2	4	4	3	3	4	4	4	4	2	4	5	5	3	3	2	4	4	5
48	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

no	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	D1	D2	D3	E1	E2	E3	E4
49	DSO	Mgr transportnetten	5	4	3	9	5	5	3	1	3	4	3	4	4	5	2	5	3
50	DSO	Adviseur DA, telemetrie, CA	5	2	3	3	3	3	3	4	3	3	3	4	2	3	2	3	9
51		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
52	DSO	Technisch specialist	5	4	2	5	4	3	2	1	1	1	3	4	4	4	2	2	2
53	TSO	Technisch specialist	2	4	4	2	3	3	1	1	2	3	4	2	9	3	9	3	3
54	DSO	Chef Technische Klantenserv	5	4	4	3	4	5	3	1	1	5	3	4	3	3	3	3	9
55	DSO	Projectleider	4	3	4	3	3	4	2	1	2	3	9	9	9	3	9	3	9
56	DSO	Sr. specialist	3	3	4	2	2	2	2	1	2	2	2	2	2	2	2	2	2
57	DSO	Manager Strategische Energ	4	3	3	2	3	3	4	2	2	3	3	3	3	4	2	3	9
58	DSO	Groepschef Werkvoorbereid	3	3	4	5	5	4	5	3	2	5	3	3	4	3	4	3	3
59		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
60		Verkoper	3	2	1	2	4	4	5	2	2	4	3	1	1	2	3	3	9
61	DSO	chef uitvoering	5	5	5	4	2	4	2	3	3	3	4	3	2	4	2	4	1
62	SUP	Hoofd R&D	5	5	4	4	5	4	3	4	2	9	4	1	4	4	9	9	9
63	DSO	Verschillende	4	3	5	3	3	4	3	2	2	2	4	2	2	4	2	2	2
64		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
65	DSO	Beleidsadviseur	3	3	4	3	5	3	4	4	2	4	3	3	3	3	2	4	9
66	DSO	Technicus primaire installatie	4	3	3	5	4	3	2	1	1	1	3	2	3	3	2	2	2
67	DSO	Technisch specialist	3	5	4	5	3	3	2	3	3	4	2	3	2	3	2	2	2
68	SUP	Proj man	3	2	4	2	2	2	2	3	1	1	3	1	1	3	2	2	2
69	SUP	Mgr Technologie	4	5	2	4	3	4	2	4	1	3	9	1	2	3	3	3	2
70	SUP	Project Manager Service	4	4	4	2	3	4	3	1	1	4	4	4	3	3	2	2	2
71	DSO	Expert	4	4	4	2	2	3	2	2	2	2	4	3	3	4	3	3	4
72		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
73	OTH	Proefleider kortsluitlab	4	4	4	4	4	4	4	1	1	1	3	4	1	4	3	4	4
74	SUP	Projectmanager	5	4	2	4	4	4	3	2	1	1	3	9	3	3	2	2	2
75		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
76	TSO	Hoofd Bedrijfsvoering	2	3	3	2	4	3	3	3	2	2	3	3	9	2	2	2	3
77		Project engineer	4	4	4	1	4	4	9	na	na	na	na	na	na	na	na	na	na
78	SUP	Directeur	4	2	2	4	2	2	2	2	2	2	2	1	1	2	2	4	2
79		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
80	SUP	Product manager secundaire	5	5	4	3	9	4	4	4	1	1	5	1	4	5	2	4	2
81	DSO	Trainee	3	4	9	4	3	5	2	1	3	1	4	9	3	3	2	2	1
82	SUP	Verkoper	4	4	4	2	2	3	3	4	3	3	4	1	1	4	3	3	3
83		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
84	OTH	Specialist beveiliging	4	5	2	4	4	5	2	4	2	2	4	5	4	4	2	3	2
85	SUP	Comm dir middenspanning	2	2	3	1	1	4	9	1	1	3	3	2	2	1	2	2	1
86	DSO	Ontwerper/Werkvoorbereid	2	9	2	2	2	3	4	3	9	9	3	2	2	2	2	3	9
87		Project Manager	4	3	3	4	2	4	5	2	3	4	na	na	na	na	na	na	na
88	DSO	Engineer	3	3	2	4	4	3	3	2	2	2	4	4	3	3	3	3	3
89	SUP	Project Leider Export	5	4	3	4	1	3	3	1	1	4	3	1	1	4	1	3	3
90	SUP	Specialist R&D	5	4	3	3	4	4	4	1	1	1	4	1	3	4	9	9	9
91	DSO	Sr. Project engineer en netpl	5	3	4	3	4	4	4	3	2	3	4	4	3	3	2	4	3
92	SUP	Sales Manager	4	4	2	5	4	4	9	2	1	4	4	2	2	4	2	3	3
93		na	1	9	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1
94	SUP	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
95	DSO	Beleidsadviseur	1	2	2	3	5	2	1	4	1	2	2	3	2	2	2	2	2
96	SUP	Directeur	5	2	4	3	4	5	3	3	1	1	na	na	na	na	na	na	na

no	E5	E6	F1	F2	G1	G2	G3	G4	G5	G6	G7	G8	H1	H2	H3	H4	H5	H6
49	4	3	TSO	Adviseur owner	5	4	3	9	3	9	2	1	1	1	5	1	1	2
50	3	3	DSO	Manager Strategie Ontwik	5	4	4	2	2	2	2	1	2	3	3	4	4	3
51	na	na		Technisch trainee	3	3	2	3	3	3	2	2	2	2	3	9	9	9
52	4	2	DSO	Beleidsadviseur	4	4	5	4	2	1	1	1	1	1	2	2	2	1
53	3	3	TSO	Projectleider	2	2	3	1	1	2	1	2	2	1	2	2	2	2
54	3	3	DSO	SR Regio Asset Specialis	5	3	5	3	3	5	5	3	1	5	5	5	5	3
55	3	3	DSO	Asset Engineer	4	3	4	3	4	3	3	4	1	2	9	9	9	9
56	2	2	DSO	Sr. specialist	3	3	3	2	3	2	2	3	2	2	2	3	3	3
57	3	9	DSO	Hoofd Standaardisatie&In	5	4	4	3	4	3	2	4	2	3	4	2	2	9
58	4	4	DSO	CMM	4	3	4	4	4	4	3	4	4	3	3	3	3	4
59	na	na		projectmanager	9	9	9	9	9	9	9	9	na	na	na	na	na	na
60	3	3		manager	5	4	4	3	4	3	1	1	2	3	2	1	1	2
61	3	2	SUP	Consultant	4	4	4	4	2	4	2	2	2	2	2	2	2	2
62	4	4	SUP	Hoofd R&D	3	3	3	2	3	2	9	1	2	3	2	1	1	1
63	4	3	TSO	Netstrateeg	4	3	2	2	3	4	2	2	2	2	3	2	2	2
64	na	na		Senior Strategie Ontwerpe	2	3	4	3	4	2	2	3	3	4	3	3	3	3
65	3	3	DSO	Beleidsadviseur	4	5	4	4	3	3	3	3	4	4	3	4	4	3
66	3	3	DSO	Engineer	3	3	4	3	3	3	4	4	2	3	3	4	4	3
67	3	2	DSO	Senior engineer / consulta	5	4	5	3	3	2	2	4	3	4	4	5	5	4
68	3	2	OTH	Sr consultant	2	3	3	4	3	3	2	3	3	3	3	9	9	9
69	4	3	OTH	GM High Power Lab	4	5	4	4	4	2	2	4	3	4	3	4	3	2
70	3	3	SUP	Projectmanager Service	5	4	5	2	4	1	1	3	1	3	9	9	9	9
71	4	3	DSO	Expert	3	4	4	2	2	2	2	2	3	3	4	2	2	1
72	na	na		Assetmanager Hoogspanr	3	4	4	4	1	2	1	2	3	3	2	2	9	1
73	4	4	TSO	Projectleider	4	3	4	3	3	3	4	3	4	1	1	3	3	3
74	3	2	SUP	Marketing Manager	4	4	5	2	3	2	2	4	2	4	4	2	3	2
75	na	na		Hoofd innovatie	5	2	4	2	3	2	2	9	9	4	2	3	3	2
76	9	3	TSO	Hoofd Systeemvoorzienin	3	4	4	2	4	3	9	9	4	4	9	4	3	9
77	na	na		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
78	2	3	SUP	Directeur	4	3	3	2	2	3	2	4	4	3	3	9	9	3
79	na	na		Algemeen directeur	5	3	4	1	3	1	1	4	3	4	2	9	9	2
80	5	3	SUP	Directeur	4	5	5	4	4	2	3	5	5	4	4	9	9	1
81	9	3	DSO	Projectleider	4	4	2	2	4	2	2	3	1	4	9	2	3	1
82	3	3	SUP	Account manager	4	4	4	2	3	4	3	3	4	3	3	3	1	3
83	na	na		Sales manager / Interim C	4	4	4	2	2	2	4	2	1	4	4	4	4	1
84	4	3	TSO	Onderhoudsstrateeg	3	4	4	2	2	4	2	3	3	4	4	4	4	2
85	2	2	SUP	Directeur	4	5	2	4	4	3	2	4	1	3	3	2	4	1
86	3	9	DSO	Adviseur kabels en garnitu	4	2	4	2	3	2	2	2	2	1	4	2	9	9
87	na	na		na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
88	3	3	DSO	Directeur	4	4	3	4	3	3	3	3	3	4	4	3	4	3
89	3	3	SUP	Area Sales Manager	4	4	3	2	4	3	2	2	3	4	4	3	4	3
90	4	3	SUP	Manager Operations Med	5	3	5	2	4	3	3	3	4	4	4	2	2	3
91	4	3		Beleidsadviseur	4	4	5	3	3	3	1	4	2	4	3	3	4	3
92	4	3	SUP	Product Line Manager	3	4	4	3	4	2	2	4	3	4	3	2	5	2
93	1	1		x	1	1	1	1	1	1	1	1	1	1	1	1	1	1
94	na	na	SUP	Salesmanager	5	5	5	4	4	4	3	3	4	5	4	1	1	1
95	2	2	DSO	Procesmanager, beleidsad	3	4	3	3	2	4	3	4	3	4	2	2	2	2
96	na	na	SUP	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

no	I1	I2	I3	J1	J2	J3	J4	K1	K2	K3	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
49	5	4	5	4	3	4	4	4	4	3	2	4	4	4	4	4	2	2	5	4
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53	3	9	9	2	2	2	2	9	9	9	3	3	3	3	3	3	3	3	3	3
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63	2	2	2	3	2	3	3	2	2	2	3	2	4	4	4	3	2	2	3	3
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66	4	9	9	3	9	3	3	9	9	9	4	2	3	3	9	9	9	9	9	9
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72	4	3	3	4	3	3	4	9	4	9	4	1	4	4	2	4	1	1	4	4
73	4	9	9	4	3	4	4	9	9	9	4	1	3	4	1	4	1	1	3	3
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75	4	1	3	3	4	3	4	1	3	3	3	3	5	2	4	3	4	2	4	4
76	4	3	9	2	2	3	2	9	9	9	2	9	4	4	3	3	9	4	4	3
77	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
78	3	1	3	3	3	3	3	1	1	1	3	3	2	3	2	2	2	2	4	4
79	4	9	3	4	3	9	3	3	1	1	5	5	4	9	4	4	2	2	4	9
80	3	1	5	5	5	1	5	5	5	1	5	5	5	5	5	2	1	1	5	5
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83	3	1	1	4	3	3	4	1	1	1	na	na	na	na	na	na	na	na	na	na
84	4	4	4	4	3	4	4	4	5	4	4	2	2	1	2	4	3	3	4	4
85	4	1	4	5	3	1	3	2	2	2	4	3	4	4	5	3	2	2	4	5
86	4	2	4	4	4	9	4	9	9	9	4	9	3	3	2	4	1	2	4	3
87	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
88	4	3	4	3	3	3	3	3	3	3	3	3	4	3	4	4	3	3	4	3
89	4	1	3	2	3	2	3	1	1	1	3	2	3	2	4	3	1	1	3	4
90	4	2	3	4	9	9	4	5	4	2	4	4	5	3	4	4	4	9	5	2
91	5	4	3	5	4	3	4	9	2	3	4	2	3	2	4	3	1	1	4	3
92	4	1	3	4	3	3	4	4	3	2	5	4	5	4	4	3	2	2	4	5
93	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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95	3	3	3	3	2	9	2	9	2	3	4	4	4	3	4	3	2	4	3	3
96	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

Summary

In this research the modernization of electricity networks in the Netherlands has been explored and explained from the perspective of (1) the alignment of the institutions and technology and (2) the innovation system. The objective of the research was to determine the important variables in the modernization of electricity networks in the Netherlands from these two analytical perspectives and to determine under which conditions these variables become important in modernization.

Research approach

The conceptual framework in the alignment perspective is a co-evolutionary approach (e.g. Nelson and Sampat, 2001; Perez, 2002; Tunzelmann, 2003) predominantly based on the theory of coherence (e.g. Finger et al., 2005; Künneke, 2008). An important aspect in this theory is the concept of critical technical functions that have to be safeguarded institutionally and technically in order to maintain an aligned system. In other words, when the function is not safeguarded the system will not function according to expectations. For instance, real time load balancing means that the production and consumption of electric power needs to be technically balanced within very short time periods of seconds or minutes. This technical need has to be supported by appropriate institutions, which is typically done by assigning certain property rights and decision rights to a system operator. If these technical needs are not sufficiently supported by institutions, this results in an unsatisfactory technical performance of the energy system. Next to alignment between institutions and technology we addressed the alignment of the different technologies in a bigger structure referred to as a large technical system (e.g. Hughes, 1987), which we refer to as 'technical' alignment. We determined the relationships between modernization and alignment with a historical analysis based on literature and expert interviews, dividing the time between the start of the first power system and the present power system accordingly in a number of periods, based on important modernizations. Additionally, we framed the important institutional variables along four layers (Koppenjan and Groenewegen, 2005) and tried to determine a 'logic' of the institutional system, which refers to the extent that the four institutional layers are complementary in shaping the institutional system.

In the Innovation Systems perspective (e.g. Freeman, 1987; Lundvall, 1992; Nelson and Rosenberg, 1993; Braczyk et al., 1998; Malerba, 2004) we also used the institutional layers to structure the identified important institutional variables and to determine a 'logic'. The institutional variables in the period prior to liberalization are compared to the institutional

variables since liberalization. We conducted interviews and a survey to capture the interactions between the institutional variables in the different layers and assessed the impact of the institutional variables on innovation. This approach also enabled us to determine which layer is important for innovation.

Results and conclusions

Alignment perspective

We identified historical examples in which the alignment of the institutions and technology acted as an important variable to modernization. Some institutions were directed at long term capacity management (i.e. the oncession scheme for provinces and the Obstruction Act) and drove the modernization, i.e. electrification of the Netherlands. We also observed historical examples that demonstrated that it was not the alignment, but the misalignment of institutions and technology which played an important driving role in the modernization of electricity networks. For example, the misaligned situation of German windmills and international interconnections overloaded and jeopardized the Dutch electricity network. This misaligned situation resulted in modernization of the network by the implementation of phase shifters. Hence, we conclude that both misalignment and alignment can act as an important variable impacting on modernization. We discussed whether there are circumstances or conditions under which modernization acts as a driver to the (mis)alignment in the system. The condition for modernization to be a driver for alignment is in cases where the technical adaptation is already to some extent readily available at reasonable costs. Although misalignment might also be answered by an institutional change, this might be more costly or too time consuming. Aligning different actors with different objectives might be costly in time, money and effort. In urgent cases it would be more appropriate to choose for an available technical solution.

Next to modernizations in which the system became re-aligned, we identified cases in which modernization of the network acted as a driver for misalignment of the system. An example also addressed above is the modernization by international interconnections which, together with the German windmills, resulted in a misaligned system. Another example is the installation of increasingly big generation plants which resulted in a substantial need for network adaptation, referred to as a technical re-alignment.

A regularity that was observed in our historical analysis relates to the network expanding to larger scales by means of interconnections: from a local to a provincial system, from a provincial to a national system, and finally from a national to an international system. Not every technical function could be easily forecasted with the growth of the electricity system. Some technology specific functions were not to be foreseen based on previous electricity network modernizations and unexpected misalignment issues resulted from that. This observation implies that with current modernization efforts, still unexpected issues can arise that would jeopardize the electricity system. This understanding is important and deviates from the standard engineering and policy making approach which focuses on the single domain of either technology or economics respectively and which is based on the idea that the system can be easily designed. Our approach shows that the electricity network should be understood as a complex socio-technical system with intricate interrelationships between the technical and institutional domain.

We determined an evolution in the logic of the electricity system from institutions directed at small scale local level in the first period of electricity system which developed into institutions directed at an integrated electricity system in the current period. From the analysis we learned that the national government has always been at a certain distance from the electricity sector with as a most remarkable example the prominent role of the provinces instead of the national government in electrifying the Netherlands in the 1910s-1930s. Although we observed that the sector at certain instances is able to solve alignment problems itself, we also observed instances were the national government stepped in to restore alignment. This indicates that per situation it should be determined at which institutional level any misalignment should be coped with. In other words, the context of the specific alignment issue is of utmost importance in determining the appropriate institutional or technical measure, an issue which needs further research.

Innovation system perspective

The application of the innovation system perspective has resulted in an inventory of important variables impacting on innovation. The interviews provided us with an enhanced understanding of the variables in modernization prior to and since liberalization. Examples of prominent variables that impact on innovation are the authority within an organization that can promote innovative activity (e.g. the CEO of the company), the culture of reliability, the share of engineers and the R&D facilities. In general we found that variables such as the culture of conservatism, the current tendering rules, the incentives for the shareholders and current regulation do not have a positive influence on radical innovation. Regulation and tendering procedures are very much focused on cost efficiency and conventional technology. We also found that to cover the risks that are accompanied with innovations more often than before extensive contractual arrangements between the technology supplier and the network company are used. With these contractual arrangements there is a tendency for technology suppliers to only provide conventional and proven technologies. This influences radical innovation negatively. It was concluded that there is a shift from long-term radical innovations to short-term incremental innovations after liberalization. The idea that liberalization increases innovation is therefore not confirmed with this research.

From the analysis of the institutional layers we learned that the central government does not steer the innovation as companies in the sector are intrinsically, in their culture and actor organization, tending towards innovation. In other words, the logic is based on self organization with regard to innovation although among policy makers there is a persistent line of thinking with regard to central planning and design. The logic, however, shows that instead of central planning and design the central government should facilitate the self regulation with regard to innovation and allow parties in the electricity sector to find the most appropriate technology. So it is not the end results which should be dictated by government policies, but the process of innovation that should be facilitated by government policies. The government should be able to intervene in cases that parties cannot fulfil their duties with regard to innovation. In order to allow for more radical innovations we suggest that the central government might opt for a more prominent role as current innovations tend to be more incremental.

If we want to increase the innovation activity of the sector we should focus on the important variables impacting on innovation as identified in this study. Policy makers and innovation managers in companies can construct innovation policies based on the key variables in the process of innovation, but should be aware that variables might work in combination with other variables and that intricate relations exist. These interrelationships, furthermore, suggest that the combination of variables might be more persuasive in explaining innovative activity than individual variables. The identified institutional variables are also highly interrelated across different institutional layers. Thus a logic combination of institutional variables, possibly at different layers, is needed to fully understand the drivers in the modernization process.

Closing remarks

Considering the above, there might be a need to accompany the institutional change to safeguard a well aligned system. In order to achieve a successful liberalized electricity sector there should be incentives to stimulate these technologies that allow for the development of a substantially decentralized electricity system. This suggestion combines both our analytical perspectives of alignment and innovation system. Radical change of the system is only needed if we want to accommodate more distributed generation and to arrive at so-called *smart grids*. The question is whether the demand pull for such radical change is large enough for the electricity sector to step in with innovations of network technology. The answer to this question should contribute to formulating a vision with regard to whether and how the government should direct its policies towards facilitating this radical change.

Samenvatting

In dit onderzoek is de modernisering van elektriciteitsnetwerken bestudeerd en beschreven vanuit het perspectief van (1) de *afstemming* (Engels: alignment) van instituties en technologie en (2) het innovatiesysteem. Het doel van het onderzoek was om de belangrijke variabelen in de modernisering van elektriciteitsnetten in Nederland te bepalen vanuit de genoemde analytische perspectieven en om te bepalen onder welke voorwaarden deze variabelen in modernisering belangrijk worden.

Onderzoeksbenadering

Het conceptueel raamwerk in het afstemmingsperspectief is een co-evolutionaire benadering (e.g. Nelson and Sampat, 2001; Perez, 2002; Tunzelmann, 2003) hoofdzakelijk gebaseerd op de theorie van coherentie (e.g. Finger et al., 2005; Künneke, 2008). Een belangrijk aspect in deze theorie is het concept van kritische technische functies die zowel technisch als institutioneel dienen te worden gewaarborgd om het systeem afgestemd te krijgen. Wanneer de functie niet is gewaarborgd zal het systeem niet volgens de verwachtingen werken. Bijvoorbeeld, real-time balancering van het netwerk betekent dat de productie en het verbruik van elektrische energie technisch in evenwicht dient te zijn binnen zeer korte perioden van seconden of minuten. Deze technische noodzaak dient te worden ondersteund door de relevante instituties, doorgaans door het toewijzen van bepaalde eigendomsrechten en beslissingsrechten van een netbeheerder. Indien deze technische behoeften niet voldoende institutioneel worden ondersteund, resulteert dit in onbevredigende technische prestaties van het energiesysteem. Naast de afstemming tussen instituties en technologie behandelden wij de afstemming van de verschillende technologieën onderling in een grotere structuur als een groot technisch systeem (e.g. Hughes, 1987), wat wij aanduiden als 'technische' afstemming. We hebben de relaties tussen modernisering en afstemming bepaald met een historische analyse op basis van literatuuronderzoek en expert-interviews, waarin we de tijd tussen het begin van de elektriciteitssystemen en het huidige systeem hebben opgedeeld in een aantal periodes gebaseerd op belangrijke moderniseringen. Bovendien hebben we hierbij de institutionele variabelen gestructureerd middels institutionele lagen (Koppenjan and Groenewegen, 2005) om een bepaalde 'logic' in het institutionele systeem bepalen, de mate dat de institutionele lagen complementair zijn in het vormgeven van het institutionele systeem.

In het innovatiesysteem-perspectief (e.g. Freeman, 1987; Lundvall, 1992; Nelson and Rosenberg, 1993; Braczyk et al., 1998; Malerba, 2004) hebben wij ook de institutionele

lagen, zoals in het afstemmingsperspectief, gebruikt om de geidentificeerde institutionele variabelen te structureren en om een logic te bepalen. Vanuit het innovatiesysteem-perspectief hebben we interviews gehouden en een survey uitgevoerd om de interacties tussen de institutionele variabelen te bepalen en om de impact van deze variabelen op innovatie te bepalen. Door deze benadering is het bovendien mogelijk geweest om te bepalen welke institutionele variabele en institutionele laag belangrijk is voor innovatie.

Resultaten en conclusies

Afstemmingsperspectief

In dit onderzoek zijn historische voorbeelden geindentificeerd waarin de afstemming van instituties en technologie een belangrijke variabele was voor modernisering. Sommige instituties waren speciaal gericht op de lange termijn capaciteitsmanagement (concessies voor de provincies en de Hinderwet) en vormden een drijvende kracht voor modernisering, namelijk de elektrificatie van Nederland. Daarnaast hebben we historische voorbeelden geidentificeerd waarin aangetoond werd dat niet de afstemming, maar juist de misafstemming van instituties en technologie een belangrijke drijvende rol speelde in de modernisering van elektriciteitsnetwerken. Een voorbeeld is de situatie van misafstemming van Duitse windmolens en de internationale interconnectoren waardoor het capaciteitsbeslag van het Nederlandse netwerk het systeem in gevaar bracht. Deze misafstemming leidde tot modernisering van het netwerk door de inzet van dwarsregeltransformatoren. Daarom concluderen we dat zowel afstemming als misafstemming kunnen fungeren als belangrijke variabelen die van invloed zijn op modernisering. Verder hebben we de omstandigheden en condities behandeld waarin modernisering een drijvende kracht kan zijn voor (mis)afstemming. De conditie waarin modernisering een drijvende kracht kan zijn voor afstemming is in gevallen waarin technische aanpassing een tijdige en kostenefficiente oplossing is voor een situatie van misafstemming Hoewel misafstemming ook beantwoord kan worden met institutionele verandering, zou dit echter duurder of tijdrovender kunnen zijn. Afstemmen van verschillende actoren met verschillende doelstellingen kan kostbaar zijn in tijd, geld en moeite. In urgente situaties zou een beschikbare technische verandering een meer adequate oplossing kunnen zijn.

Naast de modernisering waarin het systeem weer afgestemd werd hebben we gevallen geanalyseerd waarin modernisering van het netwerk een drijvende kracht was voor de misafstemming van het systeem. Een voorbeeld is de modernisering met de internationale interconnectoren die, samen met de opwekking van Duitse windmolens, resulteerden in misafstemming van het systeem. Een ander voorbeeld is de grote opwekkingseenheden die resulteerden in een behoefte aan substantiele netwerkuitbreiding, een zogenaamde technische afstemming.

Een regulariteit die we ontdekten houdt verband met netwerkuitbreiding tot grotere schaal mede als gevolg van interconnecties van verschillende individuele systemen: van een lokaal naar een provinciaal systeem, van een provinciaal naar een nationaal systeem en uiteindelijk van een nationaal naar een internationaal systeem. Niet elke technische functie kon eenvoudig worden voorzien met de groei van het elektriciteitssysteem op basis van eerdere netwerkmodernisering. Deze observering impliceert dat bij huidige moderniseringsactiviteiten ook onverwachte situaties kunnen ontstaan die het systeem mogelijk in gevaar brengen. Dit gegeven is belangrijk en wijkt af van de standaard ingenieurs- en beleidsbenadering die zich richt op technologie cq. economie en gestoeld op het idee dat het systeem eenvoudigweg ontworpen kan worden. Onze benadering toont aan dat het elektriciteitsnetwerk dient te worden begrepen als een complex sociotechnisch systeem waarin complexe interrelaties bestaan tussen het technische en institutionele domein.

We hebben verder een ontwikkeling in de logic van het elektriciteitssysteem geidentificeerd van instituties gericht op kleinschalige lokale opwekking in de beginperiode van het elektriciteitssyteem naar instituties gericht op een geintegreerd elektriciteitssysteem in de huidige periode. Uit de analyse is verder opgemaakt dat er altijd een zekere afstand is geweest van de nationale overheid tot de elektriciteitssector met als meest opmerkelijke voorbeeld de prominente rol van de provincies in plaats van de nationale overheid in de elektrificatie van Nederland in de jaren 1910-1930. Hoewel de sector bepaalde problemen zelf op kon pakken, hebben we ook vastgesteld dat op andere momenten de nationale overheid optrad om misafstemming te herstellen. Dit gegeven suggereert dat het per geval afhangt en bepaald dient te worden op welke institutionele laag bepaalde mogelijke misafstemmingen dienen te worden opgelost. Met andere woorden, de context van bepaalde specifieke afstemmingsgevallen is zeer belangrijk bij het bepalen van de meest geschikte institutionele of technische maatregel en een onderwerp wat nader onderzoek behoeft.

Innovatiesysteem-perspectief

De toepassing van het innovatiesysteem-perspectief heeft geresulteerd in een inventarisatie van de belangrijkste variabelen die van invloed zijn op innovatie. De interviews resulteerden in een beter begrip van de variabelen in de modernisering voorafgaand aan en sinds de liberalisering. Voorbeelden van belangrijke variabelen die effect hebben op de innovatie zijn de autoriteit binnen een organisatie die innovatieve activiteit kan bevorderen (e.g. de CEO), de cultuur van betrouwbaarheid, het aandeel ingenieurs in de organisatie en de R&D-faciliteiten. In het algemeen stellen we dat variabelen zoals de cultuur van conservatisme, de huidige regels op het gebied van openbare aanbesteding, de stimulansen voor de aandeelhouders en de huidige regelgeving geen positieve invloed hebben op radicale innovatie. De regulering en aanbestedingsprocedures zijn bijvoorbeeld zeer sterk gericht op kostenefficiëntie en conventionele technologie. We vonden ook dat de risico's die gepaard gaan met innovaties vaker dan voorheen worden afgedekt met uitgebreide contractuele regelingen tussen de technologieleverancier en het netwerkbedrijf. Daardoor is er een tendens voor de technologieleveranciers om alleen te voorzien in conventionele en

bewezen technologieën. Dit beinvloedt radicale innovatie in negatieve zin. We concluderen dat er een verschuiving is van lange termijn radicale innovaties naar korte termijn incrementele innovaties na de liberalisering. Het idee dat de liberalisering innovatie verhoogt, is hiermee niet bevestigd met dit onderzoek.
Vanuit de analyse van de institutionale lagen hebben we geleerd dat de centrale overheid de innovatie niet per se hoeft te sturen aangezien bedrijven in de sector intrinsiek, in hun cultuur en organisatie, al neigen naar innovatie. De logic is gebaseerd op zelforganisatie met betrekking tot innovatie terwijl er bij beleidsmakers juist een gedachte leeft van centrale planning en ontwerp. De logic laat echter zien dat in plaats van centrale planning er juist zelfregulering gefaciliteerd dient te worden om partijen in de sector de de kans te geven de meest geschikte technologien te bedenken en toe te passen. Met andere woorden, het is niet het eindresultaat dat gedicteerd dient te worden door overheidsbeleid, maar het proces van innovatie dat gefaciliteerd dient te worden. De overheid dient wel in te grijpen in gevallen waar partijen niet hun taken kunnen voldoen met betrekking tot innovatie. In geval van radicale verandering geven we aan dat de centrale overheid mogelijk een promintere rol mag hebben aangezien huidige innovaties meer incrementeel zijn.
Om de innovatie-activiteiten van de sector te vergroten dienen beleidsmakers en innovatiemanagers in bedrijven zich met hun innovatiebeleid te richten op de belangrijke variabelen zoals in deze studie blootgelegd. Ze moeten zich er echter wel van bewust zijn dat variabelen werken in combinatie met andere variabelen en dat complexe relaties tussen de variabelen bestaan. Deze samenhang tussen de variabelen is mogelijk belangrijker om bepaalde innovatie te verklaren dan individuele variabelen. De geïdentificeerde institutionele variabelen zijn ook sterk met elkaar verbonden over verschillende institutionele lagen. Er is dus een logische combinatie van institutionele variabelen, mogelijk op verschillende lagen, nodig om de drijvende krachten in het moderniseringsproces te doorgronden.

Afsluitende opmerkingen

Concluderend kan er gesteld worden dat er mogelijk een noodzaak is om de institutionele verandering te laten plaatsvinden voor een afgestemd systeem. Om een succesvolle geliberaliseerde elektriciteitssector te bereiken dienen er prikkels te zijn om de technologieen te stimuleren die de ontwikkeling van een decentraliseerd elektriciteitssysteem mogelijk maken. Deze suggestie combineert beide analytische perspectieven van afstemming en innovatiesystemen. Radicale verandering van het systeem is slechts nodig indien we meer decentrale opwekking willen accommoderen en om te komen tot zogenaamde *smart grids*. De vraag is of een marktvraag voor een dergelijke radicale verandering groot genoeg is opdat de elektriciteitssector reageert met innovaties in netwerktechnologie. Het antwoord op deze vraag draagt bij aan het formuleren van een visie met betrekking tot de rol van de nationale overheid om een dergelijke radicale verandering te faciliteren.

Curriculum vitae

Martijn Jonker holds a BSc degree in mechanical engineering and an MSc degree in Technology and Society. For his final Master's project he executed research at the Institute of Technology Bandung, Indonesia. After his graduation in 2002 he started working as a consultant for Arthur Andersen/Ernst & Young. In this job he advised consortia of national and international organizations in their extensive applications for grants and incentives for technologically innovative and energy related projects. In May 2005 Martijn returned to academia to pursue his PhD at the Delft University of Technology (TUD). Martijn has also been a visiting PhD Candidate at Carnegie Mellon University in Pittsburgh (PA), USA.
While working at TUD Martijn was an active member of the PhD Council for the faculty of Technology Poly and Management. He supervised BSc and MSc students for projects related to cost benefit analysis and institutional design and he supervised students in their final projects. Martijn also delivered a course on Technology and Economy of Energy Systems of the Future for the Master's program. Martijn has been the managing editor of the Network of Industries Newsletter (now the Network of Industries Quarterly). In 2007 Martijn has been granted the prize from the Electricité de France Foundation for his research proposal. Martijn has several publications in periodicals, books, conference proceedings and journals. In 2008 Martijn founded a company providing online printing services. In August 2009 Martijn joined the research consultancy firm ECORYS to work as a senior consultant for the unit of Energy and Climate Change.

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Martijn Jonker

Modernization of electricity networks

Exploring the interrelations between institutions and technology

Distributed generation of electricity, the aim for an integrated European electricity market and the ageing assets of electricity network are all developments that contribute to a need for the modernization of electricity networks. But how does modernization electricity networks happen? And what are important aspects to consider in the modernization of electricity networks? In this research the modernization of electricity networks in the Netherlands is explored and explained from the perspective of (1) the alignment of the institutions and technology and (2) the innovation system. The objective of the research is to determine the important variables in the modernization of electricity networks in the Netherlands from these two analytical perspectives and to determine under which conditions these variables become important in modernization. The outcomes offer valuable insights in the relationships of institutions and technology in modernization that may contribute to a better understanding of how to modernize our current electricity system.

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