S U S T E L N E T

Policy and Regulatory Roadmaps for the Integration of Distributed Generation and the Development of Sustainable Electricity Networks

LONG-TERM ELECTRICITY SUPPLY SYSTEMS DYNAMICS

A historic analysis

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Acknowledgement

Support of the European Commission
The SUSTELNET project is supported by the European Commission under the 5th RTD Framework Programme within the thematic programme 'Energy, Environment and Sustainable Development' under the contract No. ENK5-CT2001-00577, ECN project number 7.7396.

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- The Polish National Energy Conservation Agency (KAPE), Warsaw, Poland
- Hungarian Environmental Economics Centre (MAKK), Budapest, Hungary
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We would like to thank all project partners for their comments and contributions to this report, in particular Martin Scheepers and Gerrit Jan Schaeffer (ECN) and Dierk Bauknecht (Öko-Institut).

Abstract

In this report we have developed a general historical model for the development of national and European electricity supply systems. Our main thesis is that the critical problems of each era are formulated against the realities of the preceding era. Changing existing systems however is difficult, because of a technical, network related path dependency (contained within the existing electricity supply system) and a social, actor related path dependency.

We have also identified the main factors and drivers behind this process. For this purpose we have used a multi-level model, developed for analysing complex processes of socio-technical change. Each national electricity supply system can be described along four dimensions: the material infrastructure, the institutional framework, the fuel mix and the national (energy) political agenda. The major external or macro factors are: economic development, energy prices, technological development, the general drive for liberalisation, European integration, environmentalism and 'Events'. The European electricity supply system will also have a major impact on the development of national systems. Finally some implications for scenario development have been given.

CONTENTS

PREFACE

Technological developments and EU targets for penetration of renewable energy sources (RES) and greenhouse gas (GHG) reduction are decentralising the electricity infrastructure and services. Although liberalisation and internationalisation of the European electricity market has resulted in efforts to harmonise transmission pricing and regulation, no initiative exists to consider the opening up and regulation of distribution networks to ensure effective participation of RES and distributed generation (DG) in the internal market. The SUSTELNET research project provides the analytical background and organisational foundation for a regulatory process that satisfies this need.

Within the SUSTELNET research project, a consortium of 10 research organisations analysed the technical, socio-economic and institutional dynamics of the European electricity supply system and markets. This has increased the understanding of the structure of the current European electricity sector and its socio-economic and institutional environment. The underlying patterns thus identified have provided the boundary conditions and levers for policy development to reach long term RES and GHG targets (2020-2030 time frame). It was consequently analysed what regulatory actions are needed on the short-to-medium term to reach the existing medium-term goals for 2010 as well as likely scenarios for longer-term goals.

Regulatory Road Maps
The main objective of the SUSTELNET project was to develop regulatory road maps for the transition to an electricity market and network structure that creates a level playing field between centralised and decentralised generation and network development. Furthermore, the regulatory road maps will facilitate the integration of RES, within the framework of the liberalisation of the EU electricity market.

Participatory Process
To deliver a fully operational road map, a participatory regulatory process was initiated throughout this project. This process brought together electricity regulators and policy makers, distribution and supply companies, as well as representatives from other relevant institutions. This ensured a good connection with current industry, regulatory and policy practice, created involvement of the relevant actors and thereby will enhance the feasibility of implementation.

Newly Associated States
The SUSTELNET project also anticipated on the enlargement of the EU by providing support to the Newly Associated States (NAS) with the preparation of a regulatory framework and thus also with the implementation of EU Directives on energy liberalisation and renewable energy in four Accession Countries (The Czech Republic, Poland, Hungary and Slovakia).

Project Structure
The SUSTELNET project was divided into two phases. During the first phase, the analytical phase, three background studies were produced:

- Long-term dynamics of electricity supply systems in the European Union.
- Review of the current electricity policy and regulation in the European Union and in Member States.
- Review of technical options and constraints for the integration of distributed generation in electricity networks.

In the second phase, the participatory regulatory process phase two activities took place, during which there were extensive interactions with regulators, utilities, policy makers and other relevant actors:

- Development of a normative framework: criteria for, and benchmark of distribution network regulation.
- Development of policy and regulatory road maps.

This report

This report was produced during the analytical phase of the project and is part of the study on the long-term dynamics of electricity supply systems in the European Union.

EXECUTIVE SUMMARY

Aim of the study

The main objective of the analytical part of Sustelnet project is the identification of the technological, socio-economic and institutional dynamics that shape the European electricity supply systems and markets. The aim of this report is to analyse the long-term development dynamics of electricity supply systems in European nations and extract insights that can inform the building of scenario's for the development of electricity supply systems until 2020. We will address two questions:

- How can we understand the structure and use of current electricity supply systems from their historical development?
- What can we learn about possibilities and barriers to change of current systems from earlier transformations in the electricity supply sector? Which (f)actors have previously been crucial?

Analytical model

The time frame of this historical investigation is about a century. To appreciate and accommodate the socio-technical complexity of the dynamics of electricity supply systems we will use the so-called 'multi-level model' as a framework of reference. The model tries to explain the development of technology from the interplay and interaction between developments at different 'levels' of socio-technical change. It distinguishes between three levels: (1) the level of niches or protected spaces, created for enabling technological development: (2) the level of socio-technical regimes, stabilised technologies as well as practices or 'rules of the game'; and (3) the socio-technical landscape, consisting of a set of deeper structural trends and changes, or - from an actor-perspective - from external factors.

History of electricity supply systems

In a grand view on electrical history it is possible to distinguish between three eras in the development of electricity supply systems on a national level. Each era was characterized by (interrelated) elements such as leading concerns or critical problems, dominant actor groups who formulated these problems and who, put them on relevant agendas, conflicts and negotiations with other actors, and dominant designs of the supply systems. We may perhaps speak of socio-technical regimes as 'configurations' of vision, technical system building, and regulatory/institutional framework building. What is important to observe is that the shaping of each new socio-technical regime was strongly affected by the previous one: the concerns and critical problems of each era were initially formulated against the realities of the preceding era, technical developments were superimposed on the existing electricity supply infrastructure, and institutional changes departed from the established institutional framework of the previous regime. We will briefly illustrate this both for the national electricity supply systems as for the European level. Figure S.1 summarizes the main findings.

Distributed versus centralised generation

In a long-term historical perspective, the current concern or critical problem for creating a level playing field for distributed and centralized generation is remarkable. This concern seems completely opposite to the dominant critical problem in the 1950s and 1960s, which was to reduce the contribution of distributed generation to public electricity supply as much as possible in order to achieve advantages of scale. It is no surprise therefore, that current systems have an intrinsic bias towards centralised production: many actors worked hard for many decades to achieve this. Klingenberg's paradigmatic arguments for scale increase and of siting of power generation locations became much less important.

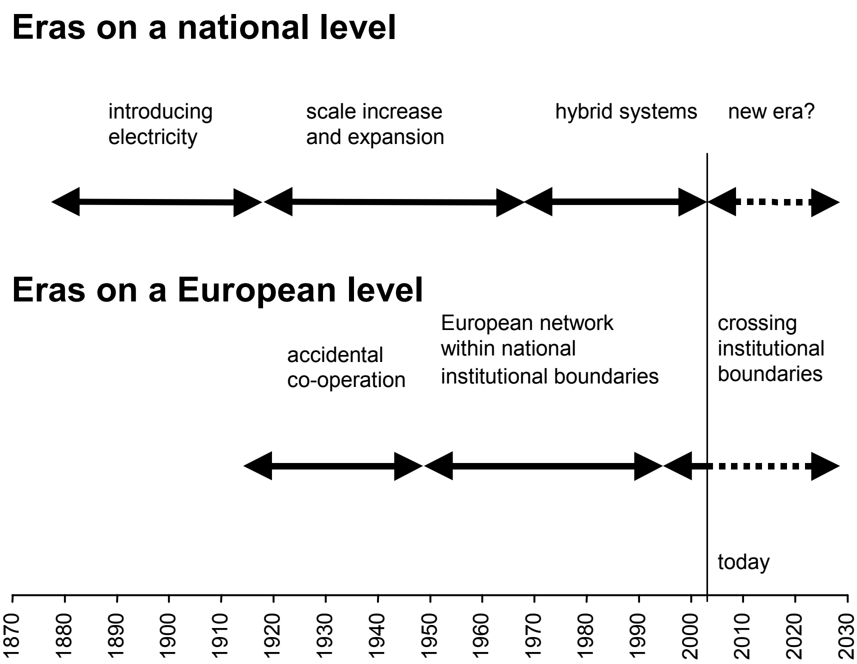

Figure S.1 *Eras in the development of electricity supply systems*

European electricity supply systems
The development of a European electricity supply system can be regarded as an extension of the development of the national systems, and initially there was no explicit attention defined for transnational networks in this project. However, the increasing influence of transnational system builders - particularly the European Union - will have major consequences for the shaping of the level playing field at local or national levels. In addition, practical co-operation across national borders (imports/exports) may put additional pressures on Renewable Energy Sources (RES) and Distributed Generation (DG). Therefore we argue that it is important to stress at least a few features the history of European electricity systems. The impact on the development of the European grid is much more uncertain. On the one hand, large scale introduction of distributed generation, both co-generation and renewable energy sources, could push for balancing demand and supply of electricity on a lower level, reducing the role of high voltage transmission grids.

On the other hand increasing exchange of electricity, exploiting differences in the availability of resources, economies of scale and favourable market conditions (e.g. cheap base load from nuclear power stations during the night) could be a factor, pushing for sustaining and expanding the European network. Engineers already have stressed that the current transmission network can become unstable if it is used for long distance high volume transmission or because calamities. Also, in the context of the TEN-program the EU has selected and financially supported several projects for the reinforcement and expansion of (inter)national connections in specific regions.

Explanatory factors
We have given a general picture of the development of electricity supply systems, both on the national and on the European level. This process (and the relation with the European level) varies for each country. Each national electricity supply system has its own dynamics and momentum, resulting also in a specific national periodisation, type of actors involved, institutional and regulatory framework etc. We have not dealt with this in detail, but instead systematically extract the main factors that seem to have guided the historical development of electricity supply systems. Although we have isolated some factors, almost always only a combination of factors and the interaction of these factors can fully explain historical developments.

We have identified a large number of factors and variables that played a major role in the development of electrical networks. There are two main categories. A first category includes factors beyond the sphere of influence of the actors involved. These external factors have been and will be more or less similar for all networks in Europe, and can be seen as general drivers in the development of scenarios.

The second category includes factors resulting from a more complex interaction between landscape and regime levels. These factors can partly explain the differences between the nations in Europe. We have operationalised this by the existing fuel mix and the national energy agenda. Together with the existing material infrastructure and the existing institutional framework these factors can be used for describing and explaining the starting situation in each European country.

Conclusions

We have developed a general historical model for the development of electricity supply systems. The next step has been to identify the main factors and drivers behind this process. We have focused mainly on the regime and landscape level and the interaction between these levels. Here we will present the main conclusions. We give also an indication of the implications of these conclusions for network development in the future.

1. Our main thesis is that the critical problems of each era are formulated against the realities of the preceding era.

In a long-term historical perspective, the current concern for creating a level playing field for distributed and centralized generation is completely opposite to the dominant critical problem in the 1950s and 1960s, which were meant to reduce the contribution of distributed generation to public electricity supply as much as possible in order to achieve advantages of scale. Current systems therefore have an intrinsic bias towards centralised production: many actors have worked hard for many decades to achieve this.

In other words: this paradigmatic shift in concerns shapes the current attempts of changing energy systems, because these systems are conditioned by a legacy from the centralisation era that created systems and institutional/regulatory frameworks exactly with a view to realising centralisation of electricity production. Consequently, the possibilities (barriers, opportunities) of DG in the current socio-technical electricity supply system are conditioned by (1) the characteristics of the system developed in the era of centralisation and (2) how actors since the 1970s have been dealing with these.

One of the explanations for this situation is that existing systems have a certain momentum or inertia, both technically and socially. Current restructuring processes will have to take this into account.

2. There exists a technical, network related path dependency (contained within the existing electricity supply system) and a social, actor related path dependency.

The existing electrical networks have created a path dependency, because of high embedded costs and large investments needed for new infrastructural developments. Examples of barriers in the existing networks are the (very) large-scale power stations, especially hydropower and nuclear power stations, because the life span of a power station often exceeds 30 years. Historically, there are two types of developing (interconnections in) electrical networks, one planned and the other gradually evolving. Both types of network development can be found, although the classical system builders (or engineers) favour designing networks. Our hypothesis is that because of the already existing networks and the reconfiguration of actor coalitions on the international level, gradually evolving network development is much more plausible than the implementation of completely new networks. Critical problems, that can induce major changes, in technical network development, focus mainly on reliability and safety issues.

Moreover there is a social, actor-related path dependency, expressed in the institutional framework at a specific moment. The institutional framework defines the roles of the different actors at a specific time and place. These frameworks have a large degree of stability. Although the current restructuring of the institutional regimes aims at changing these frameworks, restructuring processes are long-term processes. The current transition in the electricity sector did not start in the 1990s but as early as in the 1970s and will not be completed for the next two decades. Actors in the electricity supply system are important and usually do not disappear (completely). They usually stay in the business (with some exceptions) although their role can be changing, but more slowly than expected. Basically changing the institutional framework is changing the conditions for operation regulation, and in general the space to manoeuvre, or the playing field. From this perspective, deregulation does not mean fewer rules, but refers to changing the rules in favour of specific actors, increasing their options and limiting those for other actors. Moreover, history has demonstrated that the introduction of new actors creates new dynamics. Although initially their role can be limited, actors often try to expand their sphere of influence.

The combination of a technical and a social path dependency makes a continuation of the current situation probable on the short term.

There is a large variety in electrical networks, both technically and institutionally, in the countries of the EU. These differences are the outcome of historical processes. We have identified the main drivers behind these processes.

3. Each national system can be described along four dimensions: the material infrastructure, the institutional framework, the fuel mix and the national (energy) political agenda.

The electrical networks are the material basis of electricity generation, transmission, distribution and use. Each network has specific characteristics (capacity, connections etc). The institutional framework defines the roles of the actors involved, the relation between the actors and the rules of the game. Two (related) aspects that should be taken into account are the ownership structure and the role of national government. One of the main critical issues in the restructuring of the institutional framework of the electricity sector is the role of the national government (in relation to the European Union). This has a large impact both on the ownership structure and on the regulatory framework. The fuel mix in a country at a specific time results from the available resources, natural and social geography, system dynamics, political agenda and history (or path dependency). A variety of arguments have been used for the legitimisation of the development of electricity supply systems. The specific arguments vary in history and in different countries. Moreover, the energy agenda is part of (or dominated by or derived from) a more general political agenda. By using this concept we can place developments in the electricity sector in their specific political and societal context. This allows us to integrate aspects as national political structure, culture and relation to (or position) in Europe.

4. The major external or macro factors are: economic development, energy prices, technological development, the general drive for liberalisation, European integration, environmentalism and disruptive events.

Economic development can be expressed in energy demand. The development of energy prices has been especially important in regard to resource policy. ICT is an example of general technological development or multi-purpose technology. Liberalisation of major sectors of industry, supported by a dominant neo-liberal ideology, has become a key word after the collapse of the Soviet Union. Liberalisation and European integration have a major impact on the internationalisation of energy markets and the removal of institutional barriers and the development of a

European regulatory framework. Contingency is also a major constituent. Contingency can be understood as a combination of the occurrence of specific major events and the timing of these events. Disruptive events (accidents, war, crises) can have a major impact, but this impact depends on the timing of the event.

5. The European electricity supply system will have a major impact on the development of national systems.

The European dimension is not limited to the political and socio-economical developments on the European level, but it also extends to the development of a European network. The dynamics of this European network is a major factor in the future development of electrical networks in Europe. Historically, the construction of new networks (or connections between networks) often has produced unforeseen and unexpected consequences. This could well apply to the impact of the European system. Therefore, this aspect should be included in consideration on the future development of electricity supply systems in European countries.

Implications for network development
Our general reconstruction of the history of electrical systems in the European nations and on the European level provides us with three different directions for network development in the future. The basic assumption is that history has demonstrated that electricity supply systems have a very long lifespan, because of the large investments and the pattern of system development. Therefore we can assume that for the next 20 years all existing networks will still exist and be used. The crucial variable for system development is the level of balancing of supply and demand. In the current situation supply and demand are both balanced on the regional, national and international level. There are two different directions for shifting the level of balancing of supply and demand: one moving upwards in reversal of the current trend and one in the direction of more local and regional autonomy. This can be triggered by the emergence of new critical problems, e.g. by events, shortages, system failures or the factors identified as the most important drivers on the landscape level, outside the electricity system. The third scenario is a continuation of the current situation.

1. A shift to a European electric super highway system of HVDC lines and cables, combining and connecting very large scale power stations (on the long term fusion reactors) and storage capacity with interconnections to national and regional networks. In this perspective, the level of balancing will gradually shift to a higher level.

2. Less support for expansion of (inter)national grids by balancing supply and demand on the lowest level possible, creating more regional and local autonomy and maintaining only a minimum of interconnections.

3. Continuation of the current hybrid system with increased role for DG and RES, and the introduction of more interconnections. In this perspective, the balancing of supply and demand will also be of hybrid nature.

In the construction of plausible transition paths, the existing European electricity supply system and the actors involved (including the EU) will increase the chances for options one and three, where as the European gas network, and a potential future hydrogen network, could be instrumental for stimulating developments in the direction of option two.

1. INTRODUCTION

1.1 Aim and problem statement

The main objective of the analytical part of Sustelnet project is the identification of the technological, socio-economic and institutional dynamics that shape the European electricity supply systems and markets. The aim of this report is to analyse the long-term development dynamics of electricity supply systems in European nations and extract insights that can inform the building of scenario's for the development of electricity supply systems until 2020. We will address two questions:

1. How can we understand the structure and use of current electricity supply systems from their historical development?
2. What can we learn about possibilities and barriers to change of current systems from earlier transformations in the electricity supply sector? Which (f)actors have previously been crucial?

The time frame of this historical investigation is about a century. To appreciate and accommodate the socio-technical complexity of the dynamics of electricity supply systems we will use the so-called 'multi-level model' as a framework of reference (Geels, 1999; Geels and Kemp, 2000; Kemp, Schot and Hoogma, 1998 and others, see selected literature). This model distinguishes between a level of niches created for enabling technological innovation, a level of socio-technical regimes including dominant technologies and 'rules of the game', and a background level of the 'socio-technical landscape'. Technological change is explained from the interplay and interaction between developments at different levels.

We will start with a brief elaboration of this theoretical model and its relevance for the Sustelnet project. In Chapter 2 we will present an analysis of the development of electricity supply systems in European countries as well as European transnational cooperation, focusing particularly upon the regime level. In Chapter 3 we will extract constituting (f)actors of stability and change in different phases of development. Chapter 4 provides some conclusions on main development mechanisms, barriers, inertia and path dependencies and considers the consequences for scenario development.

This project has started by looking at national systems as these were considered most relevant for the implementation of RES. However, during the investigation it became clear that the interconnection of national networks into an emerging European network may have important implications for the development of electricity supply systems as well as the potential of RES. Although we have included some considerations on this European network, we were not able to elaborate this fully.

1.2 Theoretical framework and approach

The so-called multi-level model of socio-technical change was introduced in the fields of evolutionary economics and technology studies to analyse long term, structural changes (transitions or system innovations) in technology and society.

The model tries to explain the development of technology from the interplay and interaction between developments at different 'levels' of socio-technical change (see e.g. Kemp and Rip for more formal definitions). It distinguishes between three levels: the level of niches or protected spaces[1], created for enabling technological development: the level of socio-technical regimes, stabilised technologies as well as practices or 'rules of the game'; and the socio-technical landscape, consisting of a set of deeper structural trends and changes, or - from an actor-perspective - from external factors.

The starting point of our historical analysis will be the regime level. For the SUSTELNET project this is the level of the electrical networks. To further conceptualise the socio-technical character of such regimes, we will also draw upon the so-called Large Technical Systems approach (Hughes 1983, Kaijser 1998). This approach studies electricity supply systems as principally *socio-technical* systems, including hardware (the grid, power stations) as well as actors, their attitudes and definition of problems, and the institutional framework that enables them to operate, control and expand their systems. The regime level is the level of the main actors (system builders) in this project, the Transmission Network Operators (TNOs) and the Distribution Network Operators (DNOs). In this report we will not distinguish between the terms socio-technical 'regime' and 'system' to denote this level of investigation.

An essential characteristic of such regimes is that they provide the framework and guidelines for the actions and behaviour of the actors (one of the reasons to use the concept of regime). In principle those actors have the option to change the dominant rules within a regime, but in practice this is rather difficult. This is an important analytical distinction between the socio-technical regime and the socio-technical landscape. Factors on the landscape level can have enormous impacts on existing regimes, but actors operating within such a regime do not have the ability to change events on the landscape level.

On the regime level we focus on the interaction between the technical and the institutional framework. The technical framework includes in theory the entire electricity supply system including power plants (from large scale nuclear to small scale renewable energy sources), transport networks operating at various transmission and distribution voltages connected by transformer stations, the security and control system, and user appliances. The specific institutional framework of an electrical system in a country, a region or a town, includes the formal and informal laws and regulations, the organizational structure, and the ownership pattern (Kaijser 1998). So, the regulatory framework, the focus of this project, is part of the institutional framework. We will distinguish between the two in order to isolate the key variable in the SUSTELNET project, the regulation of access to the grid. In this historical sub project, we will analyse the development of the regulatory framework as a result of the interaction of technical and institutional framework in (recent) history.

In our subsequent analysis of crucial factors and variables shaping electricity supply regimes, we will address all 3 levels. On the socio-technical landscape level we may distinguish various macro factors and geographical factors, but also the general institutional framework of a country (the social and political structure and culture of a nation). The influence of factors on the socio-technical level can be both indirect and direct. An indirect impact is a general tendency in society to favour market conform and/or sustainable solutions. An example of direct influence on the regime level is a political intervention that changes (or tries to change) the institutional framework, the technical framework or both. One of the most striking examples is the agreement on the liberalisation and internationalisation of the European energy markets. Because of this the national governments are forced to change the institutional framework of the energy sector.

[1] In the multi-level model this is a called a technological niche. There are various patterns of niche developments. Some technological niches will develop into market niches and eventually become part of a new or adapted regime. Others may become obsolete and disappear, or may occupy a niche in the market only for a limited time (Hoogma et al, 2002; compare also Kaijser & Steen 1994).

The outcome of such interventions will be determined by interaction processes between the regime level and the socio-technical landscape level. The result can be quite different from what policy makers expect or want; energy systems can be less sustainable despite the intentions of the policy maker and other actors involved. This project deals only with energy policy issues addressing the electrical networks. We should add, that the demarcation of the factors (the attribution to the regime or landscape level) is to a certain degree arbitrary, because many factors are not independent variables. For instance, the fuel mix in a country at a specific time is an important characteristic of the system (the regime level). Yet this fuel mix results from the available resources, natural and social geography, system dynamics, political agenda and history (or path dependency) at the landscape level. In our framework the fuel mix therefore is a result from the interaction between the regime and the socio-technical landscape level.

On the niche level, the development of the various alternative technologies is important, e.g. the characteristics of the various alternative technologies, that are important for connecting to the grid. There are also interaction mechanisms between the socio-technical and the niche level. Important aspects are the general policy aim of sustainability and the stimulation of e.g. renewable energy sources. In this report, we will only take developments on the niche level into account, when they are relevant for the issues addressed.

Finally, we should stress that the present model is not a simple, deterministic model. It tries to reflect the complexity of the processes involved and in particular the specific framework and constraints, in which DNOs, TNOs and other relevant actors operate, and - specifically for this project - how this has changed over time. For this purpose, we have studied the historical development of the electricity supply system in a selected group of European countries (detailed studies of Denmark and the Netherlands and more general studies of Germany, France, Sweden and the European system). In this report we will present only the general findings and conclusions.

2. THE DEVELOPMENT OF ELECTRICITY SUPPLY SYSTEMS: A HISTORICAL PHASE MODEL

In a grand view on electrical history it is possible to distinguish between three eras in the development of electricity supply systems on a national level (see Figure 2.1). Each era was characterized by (interrelated) elements such as leading concerns or critical problems, dominant actor groups who formulated these problems and who, put them on relevant agendas, conflicts and negotiations with other actors, and dominant designs of the supply systems. We may perhaps speak of socio-technical regimes as 'configurations' of vision, technical system building, and regulatory/institutional framework building. What is important to observe is that the shaping of each new socio-technical regime was strongly affected by the previous one: the concerns and critical problems of each era were initially formulated against the realities of the preceding era, technical developments were superimposed on the existing electricity supply infrastructure, and institutional changes departed from the established institutional framework of the previous regime. We will briefly illustrate this for the national electricity supply systems, but the model can also be used on the European level (see § 2.2)(for references see the selected bibliography).

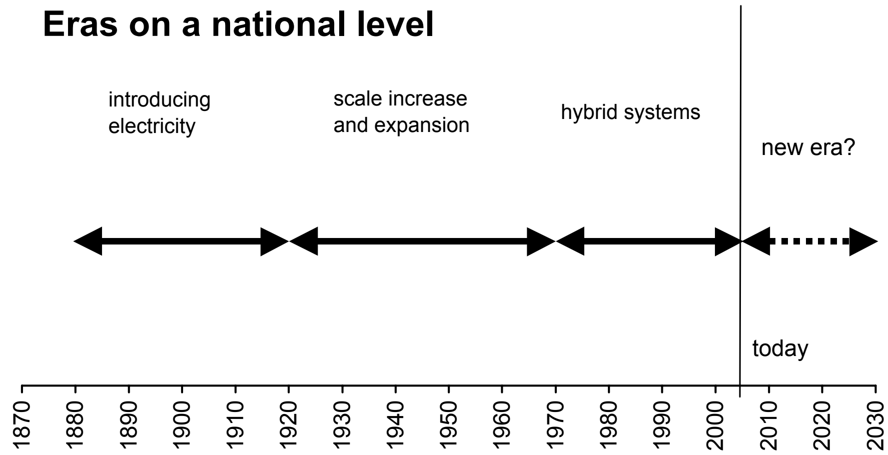

Figure 2.1 *Three eras in the development of electricity supply systems*

2.1 The development of national electricity supply systems

Introducing electricity 1880-1920[2]

Starting from scratch, the 'lead motive' of the earliest system builders constructing socio-technical electricity supply regimes was to make the new and promising power source available and earning money by selling electricity. Thomas Edison and his research group in the United States developed this original concept. Whereas electricity so far had been auto produced in lighthouses, factories or homes, Edison developed a concept of electricity supply to the public as a potentially profitable business modelled after the gas companies. This concept of 'selling electricity', at the root of the electricity supply industry as we now know it, implied a radically new design of electricity supply system (called 'local system' by historians). Electricity would

[2] The periodization gives only an indication of the timeframe. Note that there have been marked differences between the different European countries in this regard.

be generated in an ‘electricity factory’ or ‘Central Station’ (i.e. a power station); an external distribution network would take it to consumers, mostly households. Nowadays it is hardly possible to appreciate the fundamental novelty of this idea. The commercial stake showed also in the concrete design of the system: to supply households Edison invented a parallel distribution network (previous auto production systems normally had serial connections), so light bulbs could be switched on and off independently. And to make the system economically competitive with the gas companies, Edison sought to minimize the electricity current through the mains and in doing so the expenses on copper. From this commercial consideration the design specifications of light bulbs of high resistance is derived, which is now remembered as Edison’s famous ‘invention of incandescent light’. Using low voltage, direct current electricity the range of these local systems was limited to a couple of kilometres, but this was not a problem since densely populated inner city areas were the target group. Simultaneously, the commercial concept lead Edison to found a number of companies for patent holding, licence selling, equipment production and for the purpose of producing and selling electricity locally (the utility company).

This concept of a first socio-technical electricity supply system, presented at an international exhibition in Paris in 1881, was soon imitated by a host of new players, ranging from commercial companies to municipal governments and - a bit later - cooperative societies in the countryside. While the latter were mainly concerned with spreading the benefits of electricity to local communities, commercial companies and even municipalities often entered this business because of profit considerations. These were the heydays of so-called ‘municipal trading’ or ‘municipal socialism’, in which municipalities all over Europe massively engaged in business practices for the benefit of the municipal treasury.

Although most system builders originally constructed local systems, they would increasingly expand the reach of such systems by means of high voltage, alternating current transmission, locally transformed (if necessary) to user voltage in factories, households and offices. The supply configuration remained essentially the same, but extended to entire urban or rural ‘districts’. As a result of all this, the electrical map of Europe displayed a scattered variety of local and district systems.

Notably, already in this early stage the different supply options (auto production, local and district systems) might compete and clash. Already Edison got into a major controversy with his American financiers (the J.P. Morgan group) who preferred that he developed auto production systems to be produced on licence, which would entail a quicker return on investment. One of Edison’s wide-reaching decisions was to continue on the public supply track (although at least as many ‘Edison systems’ were sold to factories), which was made possible by finding European financing. Also local and district system builders might clash, district system builders seeking to get rid of local systems which supplied the population cores in their districts, the most profitable supply areas. They might buy them out, engage in fierce battles and competition, or plead for political intervention on their behalf.

Taken together, however, DG was hardly under pressure in this era, because the emerging centralised systems still had to prove themselves.

Scale increase and expansion 1920-1970

This electrical situation, which existed in many countries at a time when only a modest part of the households actually had gotten access to electricity, provides the background against which a revolutionary new paradigm was formulated and gained momentum particularly around the First World War. The fragmentation of the (material) electricity supply structure was increasingly and successfully problematised. The alternative ideal, formulated by visionary engineers and representatives of national governments (or, in Germany, by state governments), was a nationally integrated electricity supply system. Partly the idea was to make electricity available everywhere in the country, but again this was not the dominant critical problem: the advantage of national integration was formulated in terms of national-economic advantages of a national scope of the electrical supply structure.

Especially the opinions of Georg Klingenberg, Professor at the Polytechnical School of Berlin and head of the German company AEG that was recognized as one of Europe's leading, were widely quoted. Klingenberg gave four arguments for a large integrated network. The first was concentration of production in a very few, but very large power plants, in which large turbo generators produced electricity at a very low price per unit. Secondly, power plants situated near mining sites or at hydropower sites should be integrated as sources of very cheap electricity. Thirdly, as all these power stations were interconnected into one and the same system, the entire system could save on investment in back-up units. Fourthly, load managers could tune the needed electricity anywhere in the system to the overall production and thus avoid overproduction. On the institutional level, Klingenberg saw an active role of State governments in the construction of such systems, as existing players were unlikely to co-operate voluntarily.

In many countries a coalition of leading engineers and representatives of governments were at work for the realisation of this scheme. Fierce opposition came from the existing players in the field, who felt threatened in their existence. The technical and institutional/regulatory result of these negotiations varied from country to country, but it seems that 'centralisation' became the dominant ideology and subject of debate in virtually all countries. In most countries such schemes had been embedded already before the Second World War (e.g. Germany, France, and the U.K.) or immediately after (Sweden, Denmark, the Netherlands), and this paradigm reached its peak around 1970. Visions of the future were characterized by ever more centralisation, perhaps even on a European level. Also promising nuclear power possibilities pushed for further integration at least in the smaller countries.

Notably, this concern for scale increase as the privileged development route implied a new type of electricity transport system. As new power lines were built to interconnect existing systems (and their existing distribution networks) to fewer and larger power plants, a hierarchy of transport networks (primary grid, secondary grid, tertiary grid) emerged to route electricity from centralized power station to consumers. These networks, which interest us as potential input locations for RES and DG, were constructed with a completely different objective of routing centrally produced electricity and were superimposed on existing electricity supply configurations (which might be adapted, e.g. by increasing capacity or changing dc to ac distribution networks).

As part of the new norm set was to shut down decentralised production to the advantage of large scale units, DG came increasingly under pressure, although there are large differences in the degree of pressure and the timing in western European countries. Often decentralised production was almost eliminated (e.g. in the Netherlands only a few percent of total output; even in Denmark, in which DG had remained very successful still by 1950, its share was reduced to a few percent), or at least, it's role decreased significantly (e.g. in Belgium). The group of remaining auto producers mainly consisted of large companies, e.g. in the heavy chemical industry, or of companies that had access to cheap energy resources like coal (the mining industry) or hydropower. Among the exceptions was Norway, where a centralised system not yet emerged as important actors (municipalities, co-operatives, and industries) favoured local hydropower systems.

This process of scale increase and integration did not happen automatically, but was the result of persistent efforts of important actors who established new institutional frameworks to stimulate the desired changes. The role of the national government or national institutions increased in most nations, although there remained major differences in the institutional framework of various countries due to differences in political structure, political culture, and other factors. In Great Britain, France and Sweden the national government built the new superstructure. In the Netherlands small utilities had already been ousted by larger utilities, which subsequently cooperated to build a national grid keeping the national government at distance. In Denmark small utilities were integrated in larger ones and thus had become co-owners of the centralised system.

The strong tendency in favour of centralised production and the continuous increase in scale of production and transmission was matched by the same pattern in the development of consumption of electricity or more precisely, by the expectations of continuous growth. This played a decisive role in the planning of the centralised system. Moreover, these expectations proved to be correct, at least until the 1970s. Especially, the 1950s and 1960s are characterised by a rather extreme growth rate.

Hybrid systems 1970-today

The 1970s constitute a new turning point in the history of electricity supply. The energy crises and the increasing Counterculture opposition towards technocracy, centralisation and scale increase (and in particular against nuclear power) inspired governments and utilities to change policy. In the early 1980s this change became entangled with neo-liberalism and environmentalism. Governments were now concerned with diversification of energy sources (to reduce dependency on oil), energy savings (for which auto production in the form of industrial combined heat and power production was one of the many strategies next to energy saving campaigns addressed at households), and later the stimulation of renewable energy sources. Economic and environmental values, though often perceived of as opposites, might actually be combined in producing the new regime. Governments sought to stimulate this development by regulatory measures, and the material system shape started to develop in the direction of a 'hybrid system' hosting centralized as well as decentralised generation units in one and the same system. Again, the technical changes were superimposed on the existing system which remained basically intact; large power units were expanded and adapted to environmental demands, new, small units were inserted, while transport networks were only marginally adapted.

In short, we can observe no substitution, but co-evolution of centralized and decentralized systems.[3] Again, there are considerable differences from country to country. The same holds for new institutional arrangements that accompany this regime shift: in some countries the national government had already taken a central position and was able to implement the new requirements (even if this included deregulation), while in others (Denmark, the Netherlands) the state interfered for the first time in order to legally enforce desired changes. The question remains whether the liberalisation of the energy markets in the 1990s can be seen as the conclusion of this process or the start of a really new market dominated era. If the latter holds true, the third era can be seen a transition period.

In a long-term historical perspective, the current concern or critical problem for creating a level playing field for distributed and centralized generation is remarkable. This concern seems completely opposite to the dominant critical problem in the 1950s and 1960s, which was to reduce the contribution of distributed generation to public electricity supply as much as possible in order to achieve advantages of scale. It is no surprise therefore, that current systems have an intrinsic bias towards centralised production: many actors worked hard for many decades to achieve this. Klingenberg's paradigmatic arguments for scale increase and of siting of power generation locations became much less important in this era.

To understand the present challenges, it is important to acknowledge this paradigmatic shift in concerns. The current attempts of changing energy systems are conditioned by a legacy from the centralisation era that created systems and institutional/regulatory frameworks precisely with an eye to realising centralisation of electricity production. We shall (if only briefly) have to revisit

[3] This did not mean that the centralised and decentralised systems developed harmoniously. In the Netherlands, for example, the number of decentralized power stations increased substantially in the 1980s, despite strong resentments by the representatives of the dominant system, but in this case it is important that the changes in the institutional framework created new opportunities for distributed generation, or – the terms of the Sustelnet project – created a (more) level playing field.

this ‘social construction’ of the bias towards centralised productions and of barriers towards decentralised generation. In this period we expect to find path dependencies and critical decision points asked for in this project. The second event to analyse is how actors have anticipated these biases and barriers in the wake of the energy crises and liberalisation.

In sum, our hypothesis is that the possibilities (barriers, opportunities) of DG in the current socio-technical electricity supply system are conditioned by (1) the characteristics of the system developed in the era of centralisation and (2) how actors since the 1970s have been dealing with these.

2.2 The development of European electricity systems

Perhaps the development of a European electricity supply system can be regarded as an extension of the development of the national systems, and initially there was no explicit attention defined for transnational networks in this project. However, the increasing influence of transnational system builders - particularly the European Union - obviously will have major consequences for the shaping of the level playing field at local or national levels. In addition, also practical co-operation across national borders (imports/exports) may put additional pressures on RES and DG. Therefore we argue that it is important to stress at least a few features the history of European electricity systems.

As for the European electricity supply system we also can distinguish three eras, which correspond with the eras in the development of the national systems (but with a certain time lag, see Figure 2.2).

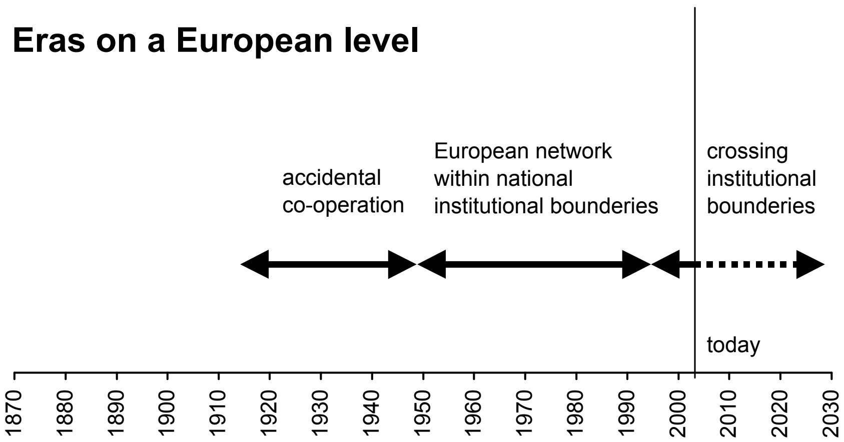

Figure 2.2 *Eras in the development of European electricity supply systems*

The era of accidental cooperation 1915-1950

Already in a very early stage border crossing connections have been established in Europe. Switzerland played a special role in this field in continental Europe. Due to its geography and abundant availability of hydropower, connections with Germany, France and Italy were established from the late 19th century. Another early example was the construction of a sub-marine cable between Sweden and Denmark (1915). Again the availability of cheap hydropower was an important incentive for this kind of power exchange. The number of international connections would gradually increase before the Second World War, but there was no systematic coupling of networks spanning more than one country.

In another area international cooperation was very important. Representatives of the various countries collaborated in the international standardisation committees like the International Electro-technical Committee (founded in 1906). In these organisations standards and requirements for electro technical equipment and machinery, power cables and lines were discussed and agreed upon. Although differences in voltage levels and systems would continue to exist in Europe, standardisation was a condition for international cooperation. This explains that connecting different systems across borders later did not create large technical problems (this does not mean that there were no problems).

Also, the first international organisations in the energy field were founded in this period. An example is the foundation of Unipede, International Union of Producers and Distributors of Electrical Energy, the organisation of the electricity industry in 1925. Another important event was the first World Power Conference in London 1924, the first of a still existing series of international conferences (in 1971 the name was change in World Energy Council). During these conferences, engineers and visionaries started to propose electricity networks for Europe in the same way their predecessors had done so on a national level. The difficult economic and political circumstances, culminating in the Second World War, prevented the further elaboration of these plans. In the Third Reich however, some engineers seriously started designing high-voltage transmission systems for Europe. One of these plans was a HVDC system, of which the first line (or cable) actually was constructed during the war. More over, the Germans started to construct lines between Germany, Belgium and the Netherlands for increasing reliability of the German system and acquiring extra production capacity. These connections were partly completed used during the war. After the war this connections would remain in use for some time. An important technical aspect was that generating stations had to be synchronised (at least in a AC-network).

A European network within national institutional boundaries 1950-1990s

After the initial focus on the reconstruction of Europe, international cooperation became one of the hot issues of the 1950s. Without going into details, we can observe the foundation of the European Economic Community (EEC), the European Coal and Steal Community (ECSC) and Euratom. At that time coal still was by far the most important energy source for the six members of the EEC, although for France and Italy hydropower (partly imported) was dominant (as for Norway, Sweden, Austria and Switzerland).

In the context of promoting cooperation in Europe the OEEC (now OECD) took the initiative for creating the Union for Coordination of the Production and Transmission of Electricity (UCPTE) in 1951. The main purpose of this organisation was to improve the interconnections between the countries in continental Europe, participating in the gradual evolving European network. A comparable organisation was formed by the Scandinavian countries and Denmark (Nordel 1963). Other organisations were involved in the process of adjusting and improving international connections, including the International Conference on Large High Voltage Electric Systems (Cigre), the International Federation of Industrial Self-Consumer Producers of Electricity (FIPACE formed in 1952).

These organisations succeeded in creating an informal system of electricity exchange. As the OEEC put it in 1957: “The liberalisation of occasional exchanges of electricity has been achieved by joint effort; in case of need a country may obtain emergency supplies from neighbouring countries, merely by putting through a telephone call and with a minimum of delay” (quoted from P.K. Lyons). Agreement was reached on 380 kV as the standard for main interconnections in Western Europe and new exchange agreements on interconnections were established with UFITPE (connecting France with Spain and Portugal), SUDEL (with south-eastern Europe through Yugoslavia, the CDO (Eastern Europe, now Centrel) through Austria and with Nordel and Finland through the Soviet Union. Exchanges however remained small in the 1950s. At a rough estimate the exported electricity in the 1950s was in the range of a few percent of total electricity consumption. The main function therefore was providing back up capacity in case of calamities or of shortages. Hydropower was an important source of reserve capacity, because it can easily be stored, but in turn during the dry season (summer), the providers of hydropower could use extra capacity from coal fired plants.

Consumption (and installed capacity) of electricity expanded rapidly, especially in the 1960s. In most Western European countries consumption doubled between 1960 and 1973, with some countries (Denmark, Ireland, Finland and Spain) showing even higher growth rates. In plans designed to meet these challenges large nuclear power stations figured prominently, but also the standard 380-400 kV connections started to look insufficient in the perspective of the industry and the organisations involved. Options were even higher voltage grids and/or HVDC- lines (or cables). (Transport over very large distances was going to the limits of the usual HVAC-connections; with distances up to 1000 km or more, power losses become significant).

Another system: the gas network

Another factor in the development of electricity supply systems should be mentioned, although beyond the scope of the SUSTELNET-project. The electricity supply system is not the only European energy system. After the discovery of large amounts of natural gas in the Netherlands in 1959 and later on the North Sea, an international gas transport system was build, now ranging from Scandinavia to North-Africa and from England and the North Sea to Russia. Historically the gas system interacted with the electricity supply system, ranging from fierce competition for markets (lighting, heating) to more symbiotic forms of interaction. The existence of a European gas network will continue to have an impact on the development of the electricity supply systems. In the extreme case, electricity supply systems will be replaced by gas or - on the long term - hydrogen distribution systems. In this vision on the future, electricity and heat can be produced by converting gas or hydrogen locally into heat and electricity, e.g. using fuel cells in micro CHPs.

Although beyond the scope of the project, it is sensible to keep this option (or more hybrid systems, combining electricity and gas systems into mind), because the interaction and competition between different energy systems can have major and unexpected impacts, as can be witnessed from the Dutch example. E.g. the process of the liberalisation of the gas markets illustrates that the gas system also displays a specific dynamics. The example of the substitution of the security of supply paradigm by a new market orientated supply paradigm, with a key role for the Dutch regulatory agency, DTe (the regulator for both the electricity and the gas market), shows that there are serious barriers for liberalisation and the new regulatory framework. DTe intervenes in a sub-market that is tightly interconnected with the wider European gas market. Whereas the gas consumer markets has embraced the logic of liberalization as the leading paradigm, in the gas supply industry long-term contracts, market stabilization and oil-parity remain the key principles for securing stable supplies in the long run. The logic is that without those long-term contracts investments in and maintenance of gas networks become very uncertain. Moreover, the main players in the gas supply industry involve three non-EU countries (Russia, Norway, Algeria) and the Netherlands. From these contrasting approaches, completely different techno-economic paradigms emerge regarding the need for and the methods of regulation and co-ordination of these markets and the preferred institutional frameworks. The implications of both ‘worlds’ are very hard to reconcile within the single framework of the Dutch regulatory agency, DTe. Indeed, many of the essential parameters for the operation of this vertically structured international industry is beyond its jurisdiction. It is also obvious that several parties, with diametrically opposed interests, try to influence the set-up of the regulatory system, referring to these different spheres of co-ordination (see Correljé and Verbong 2002).

Another complicating factor is that EU members are allowed to implement (or sustain) a national resource policy, which potentially interferes with a restructuring of the gas markets and also can have an impact on the electricity markets. The consequences of this and the potential interference with other EU policies are not yet clear. We will include the natural gas factor only when addressing the impact of the availability of natural resources and the existing fuel mix.

The oil crisis, the economic recession and the emerging social opposition e.g. to nuclear energy and the environmental impact of the electricity supply system brought an end to seemingly autonomous spiral of consumption and production growth. Several aspects of energy system became contested and government intervention increased in general (of course, depending on the role of the government in the system). Energy became an important issue on the (European) economic and political agenda, resulting e.g. in the founding of the International Energy Agency (IEA, 1974) and the establishment of European research and development programs for energy technology. Moreover, the exchange of electricity started to become more important. For the Netherlands e.g., a system of National Economic Optimalisation was established in the early 1980s. The growing emphasis on economic efficiency not only resulted in a new system of capacity planning and use, but also stimulated the import of electricity from nuclear plants in Belgium and France.

Generally speaking, the trans national network was a product of a coalition between trans national organisations and (representatives of) national organisations and governments. Similar to the national level, networking building became more contested and complicated from the 1970s onwards.

Crossing institutional boundaries 1990s - today

Essential for the second era however, was that although the European network was more and more intensely used (and was still expanding), national boundaries still provided barriers for international cooperation in production and transmission. Actors had to work and worked within their own national institutional regime. The usual way of regulating electricity exchange still was by means of contracts between specific partners, e.g. the Dutch Sep with German RWE and so on. The international organisations, constituted by national representatives, could only mediate between partners but had no real negotiation power.

The liberalisation of the European energy markets that started in the 1990s basically is removing those institutional barriers. This facilitated international cooperation, mergers and the emergence of new international actors. Existing organisations have to redefine their role and function. The Scandinavian exchange organisation Nordel e.g. is recently restructured to facilitate the establishment of an independent, commercial power pool.

The impact on the development of the European grid however is much more uncertain. On the one hand, large scale introduction of distributed generation, both co-generation and renewable energy sources, could push for balancing demand and supply of electricity on a lower level, reducing the role of high voltage transmission grids. On the other hand increasing exchange of electricity, exploiting differences in the availability of resources, economies of scale and favourable market conditions (e.g. cheap base load from nuclear power stations during the night) could be a factor, pushing for sustaining and expanding the European network. Engineers already have stressed that the current transmission network can become unstable if it is used for long distance high volume transmission or because calamities (Kling, 2002). Also, in the context of the TEN-program (Trans-European Networks) the EU has selected and financially supported several projects for the reinforcement and expansion of (inter)national connections in specific regions. This includes reinforcements in the France-Belgium-Netherlands-Germany networks in order to remove congestions, increasing electricity interconnection capacity between Spain and Portugal and between Denmark and Germany and development of infrastructure in the Balkan area in order to integrate Greece in the UCTE-system (CEC, European energy infrastructure, map on p. 24). The EU has also developed guidelines for TNOs and DNOs.

Figure 2.3 shows an overview of the combined development on the national and on the European level.

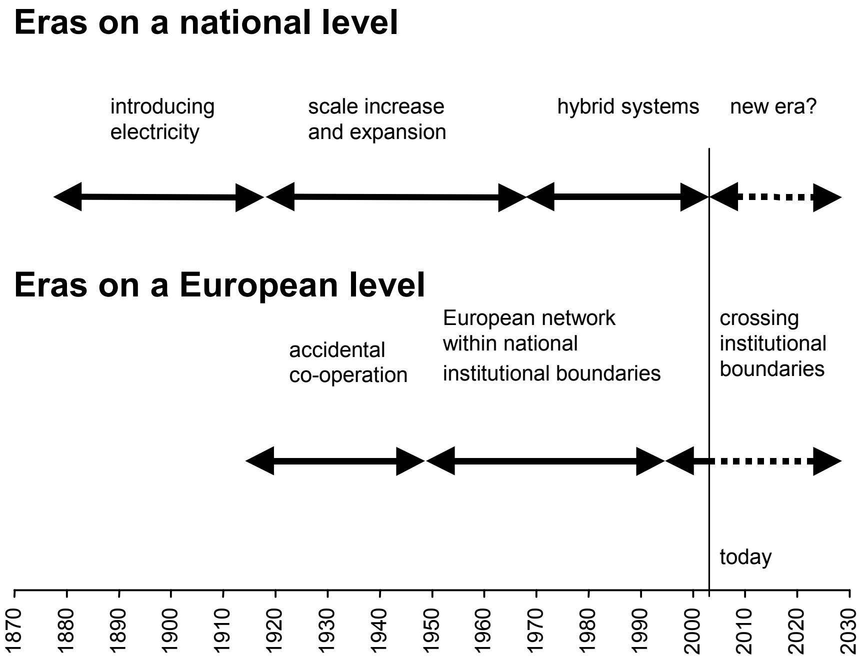

Figure 2.3 *A combined model of the development of national and European electricity networks*

3. FACTORS IN THE DEVELOPMENT OF ELECTRICITY SUPPLY SYSTEMS

Above, we have given a general picture of the development of electricity supply systems, both on the national and on the European level. This process (and the relation with the European level) varies for each country. Each national electricity supply system has its own dynamics and momentum, resulting also in a specific national periodisation, type of actors involved, institutional and regulatory framework etc. Not only was the second era completed earlier in France. The French system was also highly centralised and hierarchical, whereas in Denmark local actors, municipalities and cooperations retained a major position in the institutional framework. We will not deal with this in detail, but instead systematically extract the main factors that seem to have guided the historical development of electricity supply systems. It is important to stress that even though we will here isolate some factors, almost always only a combination of factors and the interaction of these factors can fully explain historical developments. More detailed examples can be found in separate national reports.

We will use the multi-level framework referred to in the introduction and start at the regime level. At the regime level we will focus on two major factors, the network or the material infrastructure and the institutional framework. On the landscape level, we will first analyse the factors on the national level and then proceed to analyse the European or international level.

3.1 The regime level

Network development

Despite all the differences in electric systems, there have always have been many similarities, due to the paradigmatic work of Edison and other pioneers, due to the international nature of the electro technical industry, and due to the early cooperation in the technical field (standardisations and exchange of knowledge, products and services).

A very general pattern can be distinguished. Network development started with the transmission of electricity from central power stations to one or more load centres. These were transmitting links, with the power flow in one direction only. Gradually (starting in the interwar period) networks were gradually knit together by the construction of power lines between two (or more) power stations. These were interconnecting links, with the power flow going in both directions. Especially the connection between different types of power stations was attractive, because it improved the economic mix.

There are two types of developing connections:

- Planned or designed interconnected networks.
- Evolving interconnected networks.

Examples of the first type are the construction of high voltage lines in Sweden in the interwar period and the Dutch grid (a ring structure on all voltage levels). Other examples are the various plans and designs for completely new networks, e.g. a HVDC network in Europe, but these plan have not yet materialised. Denmark, France and (to a lesser extent) Germany have provided examples of the second type. This holds for regional, national and international networks and interconnections (Hughes, Kaijser). Historically a patchwork of different layers of electrical networks have evolved, where each new higher voltage network was superimposed on the existing networks, posing specific problems for the interconnection between the various layers in the whole system. This also refers to a very important characteristic of electrical networks: usually existing lines and cables are not replaced or removed, but are integrated into the developing networks. Old networks or connections (50 years and older) are still in use! This very high degree of inertia has to be taken into account, when we consider options for developing electrical networks in the future. One of the main explanations for this inertia of course is the large investments or 'sunken costs' embedded in these networks.

The motives for constructing interconnections were economical (reducing production costs, reducing investments in back up capacity), technical (increasing reliability) or techno-economical (improving load factor). Although it is important to stress that although power links can be constructed for one purpose, they later can be used for other purposes as well. In the Dutch grid, the national grid was not designed for regular exchange, but the transmission of power gradually increased.

Another point stressed by Kaijser is the mutual shaping of power links and institutional frameworks. Power links can become catalysts for institutional change but also changes in the institutional framework can be a prerequisite for establishing new power links. Once established, these links can have unforeseen impacts (Kaijser, Nordic Energy Systems).

Institutional framework

Before the 1990s each nation developed a specific institutional framework, as a result of the outcome of a historical process within the specific social and political context. In the first era, a variety of actors played a role in all countries: private enterprises, inventors and the engineering communities, municipal and regional authorities, consumer organisations and other social groups (co operations), suppliers of equipment and machinery and last but not least, the national government. The development of the electricity supply system produced new actors, like testing and regulatory agencies, educational organisations. At a later stage, trans national actors also entered the scene. Finally, the institutional restructuring of the energy markets produced new actors (international energy companies, new regulatory agencies, energy traders, power exchanges, energy services companies) or redefined the role of existing actors. Each national institutional regime defined the roles for the actors and also defined who had access and who was excluded.

One of the major differences between the countries in Europe has been the role of the national government. Although until recently in all countries the role of the national government has become more important, there is a clear distinction between the countries where the government took the leading role or, at one stage of the development, became the dominant actor, and the other countries where this did not happen or a 'nationalisation' of the electricity supply system did not occur or was not completed. Examples of the first type are Sweden, France and the UK; examples of the second type are Denmark and Germany. The Netherlands were an exceptional case, because here at a very early stage, not the national government but the provincial authorities took over and were more or less granted the monopoly of the electricity sector.

Differences in the role of the government are also reflected in two of the most important aspects of the institutional regime, the ownership structure and the regulatory framework, defining the roles of the actors involved and the 'rules of the game'.

The specific organisational structure and the regulatory framework (including laws, regulations and procedures for grid access) in each country reflect the role of the national government (and more generally the political structure). Because of this, the process of liberalisation, aiming at the creation of a European market shows marked differences (see example in box). Those national differences will remain, although the common elements presumably will become stronger. One should stress however, that there have always been common elements both technically and institutionally.

Summarised on the regime level major factors are the existing material infrastructure (because of the inertia) and the existing institutional framework. For the last factor, it is important to map all relevant actors and their relations; the main indicators are the role of the government and the ownership structure.

Liberalisation and the heritage of the existing electricity supply system: the example of Denmark

The transformation of the Danish electricity sector sought to maintain several treats from previous Danish electricity supply regimes that were considered 'typically Danish', of course representing particular interests. For instance, the electricity reform sought to preserve state support to employment and export in the Danish wind power industry. This world leader in 1999 had a turnover of 12.5 billion DKK; exports amounted to 5.2 billion DKK (1998), while it employed 13.800 employees.

Secondly, Danish Parliament decided to maintain the influence of consumers, a tradition of co-operatives and municipalities. Supply obligation and grid companies were legally required to ensure consumer representation in the board of directors.

Thirdly, environmental concerns were maintained. Of course these were partly derived from Denmark's commitments to international treaties such as the Kyoto protocol. But the regulations especially supported the two forms of production that had build up their position in the previous regime, CHP and renewable energy, in particular wind power. The 1999 reform created a so-called 'green electricity market', in which renewable electricity producers trade electricity as well as 'green certificates' received according to supplied energy to the grid, worth of 10-27 ore/kWh. Denmark supports an internal EU market for such Renewable Energy Sources certificates.

Regarding CHP production Parliament explicitly aimed at maintaining the Danish tradition for this form of electricity production. As centralised CHP plants are regarded fully competitive, efforts to support CHP focus on decentralized CHP production. Particularly CHP systems on the level of (small) villages faced major problems in recent years and required government emergency measures to compensate the negative effects because of high natural gas prices and low electricity prices. In 2001 parties involved were discussing the possibility to introduce a certificate system comparable to that of renewable energy.

3.2 The socio-technical landscape level

We make a distinction between landscape factors on the national level and external or macro factors that have an impact on the development of all electrical networks in Europe.

3.2.1 National level

Location factors

Location factors can be related to natural and social geography. Natural geography was a major factor in the development of electrical networks. E.g. in Denmark, geography 'produced' two separate networks in Jutland and around Copenhagen. Islands proved another example of natural geography, by which network structure was determined. The Greek islands all have there own network, although the EU (or the Greek government with support of the EU), is planning to connected the island group of the Cyclades with the grid on the main land. In combination with resource availability (hydropower, coal mines), geography has been was a major stimulus for network development and high voltage transmission technology.

Social geography, the location of urbanised areas and level of industrial development were also a constituent factor in network development, because these areas (towns or industry) acted as load centres. An example of geography, shaped by political circumstances, is the electricity network of Berlin during the Cold War. In the 1950s the lines connecting Berlin with the surrounding grid were cut off. As a consequence, the Berlin electricity supply system became an island system (although remarkably, not all connections between East and West Germany were destroyed).

Resources

The availability of resources has obviously been a very important factor in the development of electricity supply systems. The most important resources for the first halve of the 20th have been coal and hydropower. Especially, the availability of large quantities of hydropower was a major driver in the development of long distance transport networks. Sweden is very good example. The first connection up north was established before the Second World War, but the real challenge was the development and construction of a 400 kV connection to Lapland, finished in 1952. This was to a large degree the result of the fruitful cooperation of Swedish companies Vattenfall and ASEA, which had already started in the interwar period.

After the Second World War new resources were introduced. First of all, there was a general transition from coal to oil, as the main energy source (and resource for the chemical industry), a process that had already started early in the 20th century. Yet, it really took off after the Second World War, when the large deposits in the Middle East were brought into production. This was complemented by the discovery of large amounts of natural gas in the Netherlands and elsewhere. By these developments nations were offered more options for their fuel mix and as result variety increased in Europe. Lack of fossil fuel resources also prompted some countries, especially France and Belgium, to a large scale introduction of nuclear energy in the 1970s.

The development of nuclear energy after the Second World War has provided another resource. In the 1950s availability of (enriched) uranium was a (political) barrier, but from the 1960s onwards, nuclear fuels have become available for most European countries. The use of nuclear energy however is the outcome of very complicated political, social and technological processes. Limited resources of uranium pushed the development of breeder reactors, a technology that has failed both for social and technological reasons. The energy crisis seemed to offer major opportunities for nuclear energy, but while in some countries nuclear energy became the major resource for the generation of electricity, in other countries social forces opposing nuclear energy resulted in a halt or even complete dismissal of this form of energy.

Moreover, resources are not a given, that is, in specific periods nations started the exploration of resources. E.g. mining in the Netherlands in the early 20th century or Denmark did have no major resources (and did not think that this was a critical problem) but this changed in the 1970s due to the general political circumstances and the active search for gas resources on the North Sea. (This is an example of an interaction between institutional framework and resources and resource policy.)

Resource policy became a crucial issue after the oil crisis and after the Limits to Growth report. Reducing dependency by diversification of resources became an integral part of energy policy (see national agenda). In this context development of renewable energy sources gradually became more prominent. Availability of resources also played an important role. The favourable wind regime in coastal areas was a factor in the implementation of wind energy, first in Denmark, later in Germany, the Netherlands, the UK and other countries. The same applies for the use of solar energy (thermal and PV). The perception of the possibilities of solar energy in North-Western Europe have changed quite dramatically after the successful demonstration of solar energy projects throughout Europe.

Socio-political factors
Socio-political factors or the general institutional framework of a country has been one of the decisive factors shaping electricity supply systems. This includes, as mentioned before, aspects like the role of the government and reflects the political culture (consensus oriented versus hierarchical in a nation. The development of electricity networks can be described as a process of mutual shaping of the specific institutional regime on one hand and the electricity system on the other. This interaction between socio-political factors and the specific characteristics of the institutional framework is a very broad and rather vague notion. We will try to operationalise this by introducing the concept of the national energy agenda (see next paragraph).

3.2.2 External factors

Economic development, expressed in demand for energy
Economic development and the resulting increased demand for electricity have played a major role in the development of electricity supply systems. Effectively, the expectations on the continuing increase in consumption have been a major argument for planning expansion of production capacity and networks. As we have argued, this was especially strong in the 1950s and 1960s. Although the extreme consumption-production spiral ended in the 1970s, there seems to be still a correlation between economic growth and the demand for electricity. E.g. in the Netherlands during the economic up swing in the 1990s the demand for electricity also started to rise again after a period of stabilisation; however the total amount of natural gas used for heating and other purposes decreased.

Energy prices
Energy prices have also been a very important factor especially in regard to resource policy. The energy crises in the 1970s stimulated energy research and development of alternative energy technology and prompted national governments to develop a resource policy. More over prices of fossil fuels, although traded on global markets, are to a substantial (high?) degree politically determined. This holds for the oil prices, where OPEC (and non-OPEC) countries try to control the oil price, but it also holds for natural gas prices. The Dutch government and the participating oil companies introduced an oil-parity pricing (or market-value price) system in order to optimise profits; in this case there is hardly any relation between costs and profits.[4]

Technological development
In the model used in this report, a large part of the relevant technological innovations take place in niches. Examples are the development of RES or conversion technologies like fuel cells. However. there is also technological development, that has no direct relation with the energy domain, but still has (potentially) a major impact on the development of electricity supply systems. This specifically applies for ICT (See Eltra/Tech-Wise, Review of the role of ICT in Network management and operations).

Liberalisation
The end of the Cold War and the collapse of the Soviet Union had major impacts on the development of Europe (and the world). Only one superpower remained and a (neo)-liberal and capitalistic ideology became the dominant political mode of thinking. This was clearly reflected in the political agenda of many governments. Liberalisation became the key word for reducing bureaucratic inertia and removing monopolies, were increasingly perceived as something ‘evil’. This was translated in the liberalisation of many policy areas and sectors, previously regarded as public domain: railways, telecommunication, energy, water, and transport. Negative experiences (railways in Great Britain) and changing political circumstances (emphasis on security and war against terrorism) have resulted in a more cautious approach of liberalisation.

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4 The large natural gas field in the northern part of the Netherlands is an example of this. Costs for gas exploration and exploitation on the North Sea were substantially higher.

This process may go either way: the liberalisation process will continue and will be completed or a reverse movement will start, with a new stimulus for more government interventions (national or on the European level, see next item).

European integration and extension
The process of European integration can be regarded as a continuous struggle between national interests and commitment to international cooperation. One of the main issues has been the question which tasks and responsibilities had to be transferred from the national to the European level, and which not. In the 1990s this process got a new impetus and the role of the EU and European organisations has increased. Recently however, resistance against (aspects of) this process has surfaced in many countries. One of the main issues is the extension of the EU with a number of countries in Eastern Europe. Also, there is still a lot of uncertainty and debate about the future shape of the EU and its organisations, e.g. a 'super state' or a more federal Europe, with responsibilities in many areas still remaining on the national (or regional) level. This will be reflected in the degree of harmonisation within the EU.

Environmentalism
In all industrialised countries (and also in the countries outside the OECD, but for other reasons) concern for the impact on the natural environment has become a major factor. In the 1970s the focus was mainly on local problems (emissions, thermal pollution of cooling water) and the limits to the resource availability, but gradually concern on more global impacts has become more important, especially the climate change problem, due to the use of fossil fuels on a very large scale. The energy sector obviously plays a very significantly role in this.

A major issue in the 1970s and 1980s has been the introduction of nuclear energy and the consequences (storage of radio active waste, waste processing); it still is at the moment in Germany. Although contested in most countries, there has been a large variety in the outcome of this process, ranging from an electricity system, dominated by nuclear power stations (France, Belgium) to countries where (almost) no nuclear power stations were introduced (Denmark, Austria) or to countries where the development of nuclear energy was halted (Netherlands, Sweden). This has been determined by the interaction of a large number of variables: availability of resources, political structure, national political agenda, institutional framework of the electricity supply system and historical timing.

These macro factors (or combinations of these factors) can be regarded as the main driving force for the development of energy systems in Europe. However, there is another kind of external factor that should be taken into account.

Contingency: events and timing
Contingency has played an intangible, but very important role in the history of electricity supply systems. Events have triggered responses from government and other actors that would have been unthinkable of in 'normal' circumstances. There are numerous examples to demonstrate this. Those events include the oil crises (a political crisis), the Harrisburg and the Tsjernobyl nuclear accidents and, more recently, the California crisis and the Enron scandal. Although events can always have a major impact, timing also plays a major role. To give just one example: The debate in Dutch parliament on the privatisation of the transmission and distribution networks was highly influenced by the California crisis and the speculation on the causes for the problems with electricity supply in California. It is not exaggerated to state (in the Dutch case) that if this crisis would have occurred a few years later, Dutch parliament would readily have agreed on selling the electricity networks to private companies. Another aspect of timing is that impact on systems is larger, when these systems are in transition or subjected to major external pressure.

Summarised: the impact of events will be determined by the (potential) impact, the state (stability) of the system and the combination (and interaction) with other major developments.

3.3 Factors resulting from the interaction between regime - and landscape factors

Fuel mix

The availability and development of resources have obviously been a major input in the fuel mix for electricity supply systems. The fuel mix in a country at a specific time is a result from the available resources, geography, system dynamics, political choices and history (or path dependency).[5] Resources and geography (e.g. distance from load centres to resources) are closely related. The intention of exploiting large-scale hydropower has been a major incentive for technological development in electricity systems. Resource integration and grid expansion are related to an 'internal' drive by system builders to improve the efficiency of electricity supply systems by incorporating resources with different and complementary characteristics, load management and increasing the variety in demand. The integration of hydropower and electricity from coal-fired stations in one system is an example of optimising load factors in systems. This kind of behaviour has according to Hughes created momentum for electricity system, although developments after 1970 have demonstrated that this is highly dependent on the degree of autonomy of system builders.

The resource policy of nations is another determinant. Although this has been much more explicit after 1970, there is long history of political influence on the fuel mix. Germany in the interwar period has provided us with a good example. Concerns about a potential coal crisis after the First World War did spur activity in mining and development of brown coal exploitation. Policy aims of autarky did create support for large wind energy projects by Herman Honnef in this era (this failed completely), but it was also taken up at the European level in the political unstable situation in the 1950s. Wind energy (briefly) was an issue on the European political agenda. A third factor is path dependency, or the consequences of historical choices. The best example is the large-scale use of nuclear energy. The supporting infrastructure, including the production of enriched uranium and the processing and storage of nuclear waste, and especially the problems of dismantling nuclear power stations will have very long term consequences. The phasing out of nuclear energy (Germany, Sweden, other countries) is a very long-term process that will have an impact on energy systems and energy policy for decades to come.

Other path dependencies are connected to the large-scale introduction of natural gas. Although gas fired stations have a much shorter time for completion, the increasing use of natural gas in households, industry and transports will have consequences for the opportunities of new technologies, including renewable energy technologies and co-generation. Competition between district heating systems with gas heating systems is a factor in this regard.

The national energy agenda

Socio-political factors or the general institutional framework of a country has been one of the decisive factors which has shaped electricity supply systems. In order to be able to operationalise these political and cultural aspects we will introduce the concept of the national political agenda and more specific, the national energy agenda. The idea behind this concept is that in legitimatising the diffusion or restructuring of electricity systems a variety of arguments have been used. These arguments have changed in history (from nationalisation to privatisation) and the combination of arguments used in a specific European country is an indication of national priorities and preferences (reflecting political culture and structure).

It also enables us to include arguments that are not directly related to electricity supply systems (or even energy policy) but can still have a decisive impact on electricity systems. Or to phrase it otherwise: the national energy agenda is derived from - and often dominated by - the broader

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[5] In this definition the choice for a specific type of power stations is also included in the fuel mix. We have made this choice because the focus in this project is on electrical networks, but of course this choice is arbitrary, because power stations form an integral part of the electricity supply system.

national political agenda. (That is why we put this on the landscape level, although obviously the discursive aspect of electricity systems is an important part of the regime level). Clear examples are the military and super power motives for stimulating the use of nuclear energy or, more generally, industrial and social policy arguments, like creating opportunities for national industry or maintaining employment e.g. in coal mining.

Summarised, energy politics have to be put in the context of a more general political national agenda. The same can be said of the European level, e.g. energy issues (coal, atomic energy, co-ordination and facilitation of transmission of electricity) were used as a tool for stimulating European integration in the 1950s. Of course, the national agenda is a simplified reflection of national identities and characteristics, because different actor groups (e.g. new governments) can have different agenda's, but we regard the national agenda as the outcome of the process of national agenda building.

In the first era of electricity supply systems the major argument legitimising electricity systems was that access to a new source of lighting and power should be open for everyone. This played a major role in creating regional and national grids, including less developed and populated areas (rural areas). Also, for private enterprises commercial motives were important (new markets, new opportunities).

In the second era new arguments were dominant:

- Economies of scale in production and transmission. The classic system builder arguments, often supported by (national) governments. These arguments were especially strong in the 1950s and 1960s.
- Reliability has been another major argument for system expansion. Although in the first place an engineering argument, this has also been adopted by governments. National economies had become increasingly dependent on a reliable electricity supply system.
- Providing electricity as cheap as possible. This was mainly a concern of governments and of large consumers.
- Military, political and industrial arguments. Although much less explicit, these kinds of arguments have been used after the Second World War, especially in difficult political and economic circumstances.

In the third era some new arguments have been added:

- Reducing international dependency.
- Reducing environmental impacts and the intended transition to more sustainable energy systems.
- More market orientation and liberalisation of energy markets.
- Privatisation and deregulation (redefining the role of the government).

Although such arguments have been extensively used, one should reflect critically on the underlying assumptions. E.g., one might look at the arguments used for the legitimisation of DG. The main arguments, as expressed in the literature, are that DG provides cheaper electricity, improves reliability of the supply system and reduces environmental impacts. It is important to stress that these arguments were developed in an American context within a completely different system of electricity supply and different institutional framework. Surprisingly however, these arguments were quickly adopted in Europe without much discussion or critical reflection on the issue whether these arguments are also valid for the European situation. The environmental argument obviously also holds for the European situation, but the cost structure and the reliability of the electricity supply system in the European situation differ substantially from the American one.

Now for each nation a specific combination of legitimising arguments can be made. For the Netherlands e.g. securing supply (reliability) and low prices (economic stimulus) were major arguments for legitimising and shaping energy policy. Industrial policy was an indirect but influential factor too. After 1970 diversification and resource policy (reducing dependency) became the third policy starting point, gradually complemented by environmental goals. The gas reserves played a major role in shaping Dutch policy. Until recently, European integration has been a ‘no issue’ for Dutch politicians (something that they took for granted), contrary to the Danish, who had always had a more ambiguous attitude to Europe. France is an example of a completely different combination of arguments and choices. The highly centralised state is reflected in the institutional framework of the electricity sector, dominated by the state company EdF. France embarked on the nuclear road, to reduce dependency on fossil fuels, but this was ‘fuelled’ also by international military and political ambitions (and also, but to a lesser extent, by industrial considerations). For France the position in Europe and, especially to the other powers UK and Germany, also had a decisive impact on French policy.

3.4 The European dimension

The focus has been mainly on the development of national electricity networks. During the 20th century these networks gradually have become entangled by a growing number of interconnections. Because of this a kind of European electricity supply system has emerged, as we have seen in section 2.2. This system has also displayed a specific dynamics that can be analysed with the same analytical framework, we have developed in this report. For the material infrastructure, covering and connecting almost all parts of Europe, the same applies as for the national networks: because of existence they have inertia. Moreover, actors are actively trying to expand these networks. This includes the EU, e.g. the TEN-program, but there are a variety of actors, such as large industrial companies and utilities, but also standardisation and lobby organisations, involved in this process.

Especially the creation of a European market and the removal of institutional barriers (one of the objectives of the liberalisation process) will give a strong impetus to the expansion of the European dimension of electricity networks. The creation of an internal European market presupposes the possibility of large-scale exchange of electricity in Europe. This certainly will have an impact on the development of the national electricity networks. This has to be taken into account.

Liberalisation of energy markets is part of the European energy agenda. Stimulating or protecting RES and DG in general are also part of this agenda and fits within the broader political agenda of the EU. The energy policy of the EU is:
- Instrumental for European integration by stimulating cooperation and the creation of markets (1950s, 1990s).
- Instrumental for European industrial and social policy.
- Instrumental for environmental policy (climate change).

Even more general policy objectives are increasing the European independency and enhancing Europe’s international position. One should bear in mind, that not all parties involved share or agree with (all) those objectives, but it seems to be quite certain that the influence of the European level on the national level will increase in the nearby future.

3.5 Conclusions

We have identified a large number of factors and variables that played a major role in the development of electrical networks. There are two main categories. A first category includes factors beyond the sphere of influence of the actors involved. These external factors have been and will be more or less similar for all networks in Europe, and can be seen as general drivers in the development of scenarios.

The second category includes factors resulting from a more complex interaction between landscape and regime levels. These factors can partly explain the differences between the nations in Europe. We have operationalised this by the existing fuel mix and the national energy agenda. Together with the existing material infrastructure and the existing institutional framework these factors can be used for describing and explaining the starting situation in each European country.

4. SUMMARY AND CONCLUSIONS

In this report we have developed a general historical model for the development of electricity supply systems. The next step has been to identify the main factors and drivers behind this process. For this purpose we have used a multi-level model, developed for analysing complex processes of socio-technical change. We have focused mainly on the regime and landscape level and the interaction between these levels. In this paragraph we will present the main conclusions. We will also give an indication of the implications of these conclusions for network development in the future.

1. Our main thesis is that the critical problems of each era are formulated against the realities of the preceding era.

In a long-term historical perspective, the current concern for creating a level playing field for distributed and centralized generation is completely opposite to the dominant critical problem in the 1950s and 1960s, which were meant to reduce the contribution of distributed generation to public electricity supply as much as possible in order to achieve advantages of scale. Current systems therefore have an intrinsic bias towards centralised production: many actors have worked hard for many decades to achieve this.

In other words: this paradigmatic shift in concerns shapes the current attempts of changing energy systems, because these systems are conditioned by a legacy from the centralisation era that created systems and institutional/regulatory frameworks exactly with a view to realising centralisation of electricity production. Consequently, the possibilities (barriers, opportunities) of DG in the current socio-technical electricity supply system are conditioned by (1) the characteristics of the system developed in the era of centralisation and (2) how actors since the 1970s have been dealing with these.

One of the explanations for this situation is that existing systems have a certain momentum or inertia, both technically and socially. Current restructuring processes will have to take this into account.

2. There exists a technical, network related path dependency (contained within the existing electricity supply system) and a social, actor related path dependency.

The existing electrical networks have created a path dependency, because of high embedded costs and large investments needed for new infrastructural developments. Examples of barriers in the existing networks are the (very) large-scale power stations, especially hydropower and nuclear power stations, because the life span of a power station often exceeds 30 years. Although countries like Sweden and Germany have embarked on a road of phasing out nuclear energy, this is a very long-term substitution process. The existing grid infrastructure also poses barriers for DG, because the design of those systems does not accommodate decentralised power stations. Changing those networks demands both technological adaptations and large investments. Historically, there are two types of developing (interconnections in) electrical networks, one planned and the other gradually evolving. Both types of network development can be found, although the classical system builders (or engineers) favour designing networks. Our hypothesis is that because of the already existing networks and the reconfiguration of actor coalitions on the international level, gradually evolving network development is much more plausible than the implementation of completely new networks. Critical problems, that can induce major changes, in technical network development, focus mainly on reliability and safety issues.

Moreover there is a social, actor-related path dependency, expressed in the institutional framework at a specific moment. The institutional framework defines the roles of the different actors at a specific time and place. These frameworks have a large degree of stability. Although the current restructuring of the institutional regimes aims at changing these frameworks, restructuring processes are long-term processes. The current transition in the electricity sector did not start in the 1990s but as early as in the 1970s and will not be completed for the next two decades. Actors in the electricity supply system are important and usually do not disappear (completely). They usually stay in the business (with some exceptions) although their role can be changing, but more slowly than expected. Basically changing the institutional framework is changing the conditions for operation regulation, and in general the space to manoeuvre, or the playing field. From this perspective, deregulation does not mean fewer rules, but refers to changing the rules in favour of specific actors, increasing their options and limiting those for other actors. Moreover, history has demonstrated that the introduction of new actors creates new dynamics. Although initially their role can be limited, actors often try to expand their sphere of influence.

The combination of a technical and a social path dependency makes a continuation of the current situation probable on the short term.

There is a large variety in electrical networks, both technically and institutionally, in the countries of the EU. These differences are the outcome of historical processes. We have identified the main drivers behind these processes. For the construction of scenario's we have combined those factors or drivers into a few dimensions or categories

3. Each national system can be described along four dimensions: the material infrastructure, the institutional framework, the fuel mix and the national (energy) political agenda.

The electrical networks are the material basis of electricity generation, transmission, distribution and use. Each network has specific characteristics (capacity, connections etc). The institutional framework defines the roles of the actors involved, the relation between the actors and the rules of the game. Two (related) aspects that should be taken into account are the ownership structure and the role of national government. One of the main critical issues in the restructuring of the institutional framework of the electricity sector is the role of the national government (in relation to the European Union). This has a large impact both on the ownership structure and on the regulatory framework. The fuel mix in a country at a specific time results from the available resources, natural and social geography, system dynamics, political agenda and history (or path dependency). A variety of arguments have been used for the legitimisation of the development of electricity supply systems. The specific arguments vary in history and in different countries. Moreover, the energy agenda is part of (or dominated by or derived from) a more general political agenda. By using this concept we can place developments in the electricity sector in their specific political and societal context. This allows us to integrate aspects as national political structure, culture and relation to (or position) in Europe.

4. The major external or macro factors are: economic development, energy prices, technological development, the general drive for liberalisation, European integration, environmentalism and disruptive events.

Economic development can be expressed in energy demand. The development of energy prices has been especially important in regard to resource policy. ICT is an examples of general technological development or multi-purpose technology. Liberalisation of major sectors of industry, supported by a dominant neo-liberal ideology, has become a key word after the collapse of the Soviet Union. Liberalisation and European integration have a major impact on the internationalisation of energy markets and the removal of institutional barriers and the development of a European regulatory framework. Contingency is also a major constituent. Contingency can be understood as a combination of the occurrence of specific major events and the timing of these events. Disruptive events (accidents, war, crises) can have a major impact, but this impact depends on the timing of the event.

5. The European electricity supply system will have a major impact on the development of national systems.

The European dimension is not limited to the political and socio-economical developments on the European level, but it also extends to the development of a European network. The dynamics of this European network is a major factor in the future development of electrical networks in Europe. Historically, the construction of new networks (or connections between networks) often has produced unforeseen and unexpected consequences. This could well apply to the impact of the European system. Therefore, this aspect should be included in consideration on the future development of electricity supply systems in European countries.

Implications for network development

Our general reconstruction of the history of electrical systems in the European nations and on the European level provides us with three different directions for network development in the future. The basic assumption is that history has demonstrated that electricity supply systems have a very long lifespan, because of the large investments and the pattern of system development. Therefore we can assume that for the next 20 years all existing networks will still exist and be used. The crucial variable for system development is the level of balancing of supply and demand. In the current situation supply and demand are both balanced on the regional, national and international level. There are two different directions for shifting the level of balancing of supply and demand: one moving upwards in reversal of the current trend and one in the direction of more local and regional autonomy. This can be triggered by the emergence of new critical problems, e.g. by events, shortages, system failures or the factors identified as the most important drivers on the landscape level, outside the electricity system. The third scenario is a continuation of the hybridisation of electricity supply.

1. A shift to a European electric super highway system of HVDC lines and cables, combining and connecting very large scale power stations (on the long term fusion reactors) and storage capacity with interconnections to national and regional networks. In this perspective, the level of balancing will gradually shift to a higher level.

2. Less support for expansion of (inter)national grids by balancing supply and demand on the lowest level possible, creating more regional and local autonomy and maintaining only a minimum of interconnections.

3. Continuation of the current hybrid system with increased role for DG and RES, and the introduction of more interconnections. In this perspective, the balancing of supply and demand will also be of hybrid nature.

In the construction of plausible transition paths, the existing European electricity supply system and the actors involved (including the EU) will increase the chances for options one and three, where as the European gas network, and a potential future hydrogen network, could be instrumental for stimulating developments in the direction of option two.

LIST OF ABBREVIATIONS[6]

CIGRE	International Conference on Large High Voltage Electric Systems
DG	Distributed Generation
DNO	Distribution Network Operator
ECSC	European Coal and Steal Community
EEC	European Economic Community
FIPACE	International Federation of Industrial Self-Consumer Producers of Electricity
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IEC	International Electro-technical Committee
MS	E.U. Member State
OEEC	Organisation for European Economic Cooperation (now OECD)
RES	Renewable Energy Resources
TNO	Transmission Network Operator
UCPTE	Union for Coordination of the Production and Transmission of Electricity (now UCTE)
Unipede	International Union of Producers and Distributors of Electrical Energy

[6] Some of the abbreviations have been derived from the French name of the organisation.

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