To be presented at the 10th international conference of the Greening of Industry Network
June 23-26, Göteborg, Sweden

Governance and Sociotechnical Change in the Electricity System

Paper for the 10th Greening of Industry Network Conference
Göteborg, 23-26 June, 2002

PETER S. HOFMAN

Center for Clean Technology and Environmental Policy
CSTM University of Twente
P.O. Box 217
7500 AE Enschede
The Netherlands
Tel + 31 53 4894541 Fax +31 53 4894850
Email: P.S.Hofman@cstm.utwente.nl

Keywords: Electricity, Sociotechnical change, Path dependence, Regime transformation

Abstract

This paper analyses developments of the past three decades in the Dutch electricity system in the perspective of co-evolution of technological and societal development. The electricity system based on fossil-based, large-scale, technology and a relatively closed social network is changing towards a much more diverse system in terms of actors, sources and technologies. The paper explains how developments in the institutional set-up, technological base, and societal preferences and problems, underlie this process of change and provide opportunities for modulation of electricity generation and use in a climate friendly direction. The paper focuses on developments in governance which have had considerable implications for the electricity regime. The mode of governance based on autonomy and a natural monopoly has long been a good match the dominant design of the electricity regime: the central station electricity system. The change of mode of governance towards liberalisation creates pressure on guiding principles of the central station electricity system and gives opportunities for an increase of the diversity of actors and modes of provision within the electricity system. Examples are the emergence of decentral combined heat and power production and the emergence of green electricity that can be explained through shifting actor strategies. A coalition of diverse actors has proven to be very effective in spreading these concepts throughout the electricity system. The role of policy has been significant in this process but secondary to governance changes, which will be highlighted in the paper.

On the one hand the paper interprets the theoretical relevance of this case by linking it to transition theory that aims to explain why and how regimes change and/or transform. On the other hand the paper aims to have practical relevance by providing insight how the current flux in the electricity regime provides seeds for paths towards a more sustainable electricity system.

1. Introduction

The generation of electricity in the Netherlands and the rest of the world makes a major contribution to CO_2 emissions and thus to the climate problem. In the Netherlands it contributes 26% of CO_2 emissions, while the global figure for carbon emissions is 37.5%.[1] There is now growing recognition that the electricity system needs to shift away from its fossil basis, but the actual result of policies towards realising that changeover have been disappointing. In this paper it is argued that realising the shift towards renewable sources is especially difficult because it not only involves new technologies but also changes in user practices, legislation, policy, infrastructure, networks, and institutions, i.e. it implies a combination of technical and social change. It is difficult to change the direction of technological developments in the electricity system since, over decades, elements such as technology, infrastructure, knowledge, regulation, industrial organisation and user preference have become mutually attuned, leading to a tightly-knit system based on large-scale, centralised, fossil-fuelled electricity generation. In social studies of technology the term 'technological regime' has been introduced to describe the way weak and strong linkages occur between the different elements, which act as a semi-coherent structure for the development of both technological and social components in a system (Kemp, Rip and Schot, 2001).

This paper is based on research carried out in the Matric project[2] that studied how the interaction between technological and societal developments has shaped the system of generation, transport and use of electricity. The analysis concerns how the predominance of central, large-scale, fossil-fuelled electricity generating stations, in association with the closed network of electricity actors, has long impeded the introduction of alternatives. The processes of liberalisation, increasing environmental and climate pressures and the emergence of niche technologies led to an opening up of the closed electricity network. It led actors to develop new strategies and coalitions, and facilitates paths towards a much more diverse electricity system in terms of actors, sources and technologies.

On the one hand the paper interprets the theoretical relevance of this case by linking it to transition theory that aims to explain why and how regimes change and/or transform. On the other hand the paper aims to have practical relevance by providing insight how the current flux in the electricity regime provides seeds for paths towards a more sustainable electricity system.

[1] ECN, Energieverslag Nederland 2000 [Netherlands Energy Report 2000], p. 112; IPCC, Climate Change 2001, Mitigation, section 3.8.1.

[2] Matric: Management of Technology Responses to the Climate Change Challenge. The project was funded by the National Research Programme on Global Air Pollution and Climate Change (NOP) and was carried out by a consortium of the University of Twente and MERIT. This article is based on the report by Hofman and Marquart (2001). Other projects focused on transport and design for the environment, Arentsen and Eberg (2001) provide a synthesis report of the project.

2. Path dependence, regime change and transformation

Sociotechnical change theory advocates the integrated study of society and technology and has provided insights on the way technology evolves in society and social shaping of technology occurs (Bijker et al., 1987, 1995; Williams and Edge, 1996; Rip and Kemp, 1998). It considers technological change not as a rigid, categorised, process but as a multidirectional flux that involves constant negotiation and renegotiation among and between groups shaping the technology (Pinch and Bijker, 1987). Technology is shaped by social, economic, cultural and political forces and in the same process technology shapes human relations and societies (Rip and Kemp, 1998). This co-evolution is often path dependent in the sense that configurations of technology entrenched in social processes, consumption patterns, and lifestyles are difficult to reverse. Also economic mechanisms such as increasing returns to adoption have path dependent features. Examples are the technological interrelatedness of various technologies and products in fossil-based electricity generation and transmission infrastructure, and informational increasing returns (Arthur, 1988). The concept of path dependence is also useful in order to explain why, despite clear intensification of the climate pressure, policies have not been able to foster fundamental changes in generation and use of electricity. Technologies and policies initiate from the accumulated knowledge, institutional structures, and competencies of the existing electricity system and are unable to deviate from the fossil-based technological trajectory. Sociotechnical change theorists particularly explore how technologies and artefacts are both products and sources of these path dependencies. Both technological and regulatory development can become locked in a path of gradual improvement of dominant systems and are, consequently, unable to bring forth fundamental systems change.

While path dependence explains how technological trajectories become more or less rigid, and technological systems become stable, also path creation occurs, leading to the development of new technological trajectories, new regimes (e.g. computer regime), and the transformation of existing regimes. Transition theory, building upon insights from evolutionary economics, social studies of technology and innovation studies, aims to explain the transformation of regimes. The theory integrates dynamics at three 'levels':

1. The *socio-technical regime*: socio-technical systems that derive stability from the interweaving of technologies, policies, user preferences and infrastructures. Innovation in a socio-technical regime usually leads to incremental change along stabilised technological trajectories.
2. The *socio-technical landscape*: this refers to the external 'macro' environment with processes such as cultural developments, climate-policy, (oil) crises, liberalisation, etc.
3. *Technological niches*: this refers to emerging 'alternative' technologies which provide the seeds for change.

Usually the regime is stable, and niches have no chance to break through. Regime transformation can occur when dynamics at three levels link up. When landscape developments put pressure on the regime, opportunities are created for the breakthrough of new technologies or concepts. Alternative trajectories can emerge and accelerate when the regime is opening up. Transition theory has been used to study historical transitions, leading to further insights about patterns and mechanisms and the circumstances under which they occur. It also points to social networks as key to both the stabilisation of present technologies and, potentially, the creation of new ones (Weaver et al., 2000). Path dependence can occur due to routinised behaviour and R&D trajectories that become fixed around dominant guiding principles. As problem definitions become shared within a network a powerful constituency is developed that perpetuates its technology. Based on experiences of a program on sustainable technology development Weaver et al. (2000) argue that new directions for R&D might be found by creating new cross-sectoral networks around innovation challenges, and by helping network members to redefine innovation challenges in new terms. In our case study of the electricity regime this mechanism has played a role in redefining the development of gas turbine development for aircrafts towards electricity generation as alliances between aircraft firms and power companies were formed.

This paper further explores developments in the electricity regime with the concepts of regime stability and change. It shows how the stable electricity regime gradually lost its stability as landscape pressures and niche developments led to increasing tension in the regime. The paper then continues with an interpretation of these tensions, landscape and niche developments and its potential for transforming the electricity regime.

3. From stability to flux in the electricity regime

3.1. The origins of the electricity regime: the central station electricity system

Thomas Edison is generally recognised as the founding father of the modern electricity system with his path breaking system's approach of electricity generation and distribution (Hughes, 1983). He perfectly understood that "If what you are selling is illumination and you want to make it as economical as possible, you have to optimise the entire system – the generator, the network and the light bulbs – as a system, because it all works together, moment by moment" (Patterson, 1999: 142).

The secrets untangled by Thomas Edison and his successors enabled the construction of the central-station electricity system as we know it today. Electricity production, transmission and consumption is a well integrated system with a large set of interconnected technological components, most often highly complex themselves. The development of this central-station electricity system took more than a century and went through different stages:

"The Edison direct-current systems of the first stage were characterised by homogeneity of supply and load. The systems of the second phase were more heterogeneous. They were characterised by the concept of transmission and distribution introduced at the 'universal system' at the Chicago exposition of 1893. (…) The regional systems of the 1920s can be categorised as the third stage in the evolution of electricity supply. Again the hallmark is increased heterogeneity. Whereas in the universal system of the second stage, different kinds of loads were systematically jointed according to the concept of load factor, in the third stage, different kinds of energy sources were combined according to the more recently articulated concept of economic mix. (…) Turbines and high voltage transmission stimulated the construction of far-flung systems, and the spread of these was so extensive as to include natural resources of various kinds" (Hughes, 1983: 366).

The system's optimisation at an ever increasing scale, maintaining reliability and reducing operation costs, have been ultimate drivers in the technological development of the electricity system until the 1970s. The regime featured stable growth paths based on increasing returns to scale for steam turbines, monopolistic organisation that secured payback of large scale investments in power plants, growth of electricity demand due to economic growth and electrification (network externalities), and policies towards security of resource supply. Electricity producers aimed at expanding and improving the system and worked "to decrease outside influences so they could acquire greater control over elements that might have destabilized their rule. (They) achieved closure partly by encouraging the creation of conservative inventions, such as steadily improving steam-turbine generators, which originated within the system and reinforced the authority held by the existing elites" (Hirsh, 1999: 3). From the seventies on, the closed and central character of the electricity regime was increasingly challenged due to the building up of external pressure and changes within the regime.

3.2 Change in the electricity regime, 1970-1980

Gas turbine technology was invented in the early 1900s at a time that steam turbine technology was already dominating electricity generation. Especially during and after the second World War gas turbine technology was further developed in its application to jet engines. Extensive R&D efforts in the military-industrial complex paid off in developing more powerful gas turbines with abilities to deliver power quickly. Several companies who had been involved in the development of the aircraft turbines for military jets and also had expertise in the field of steam turbines were able to "adapt and market the uses of the gas turbines in other economic activities" (Islas, 1997: 55). From the end of the sixties on gas turbines are introduced in electricity generation in the Netherlands.

From a technology dynamics perspective the emergence of the gas turbine is very relevant since the gas turbine was able to get around the lock-in of electricity generation towards steam turbine technology. Various factors facilitated the introduction of the gas turbine:

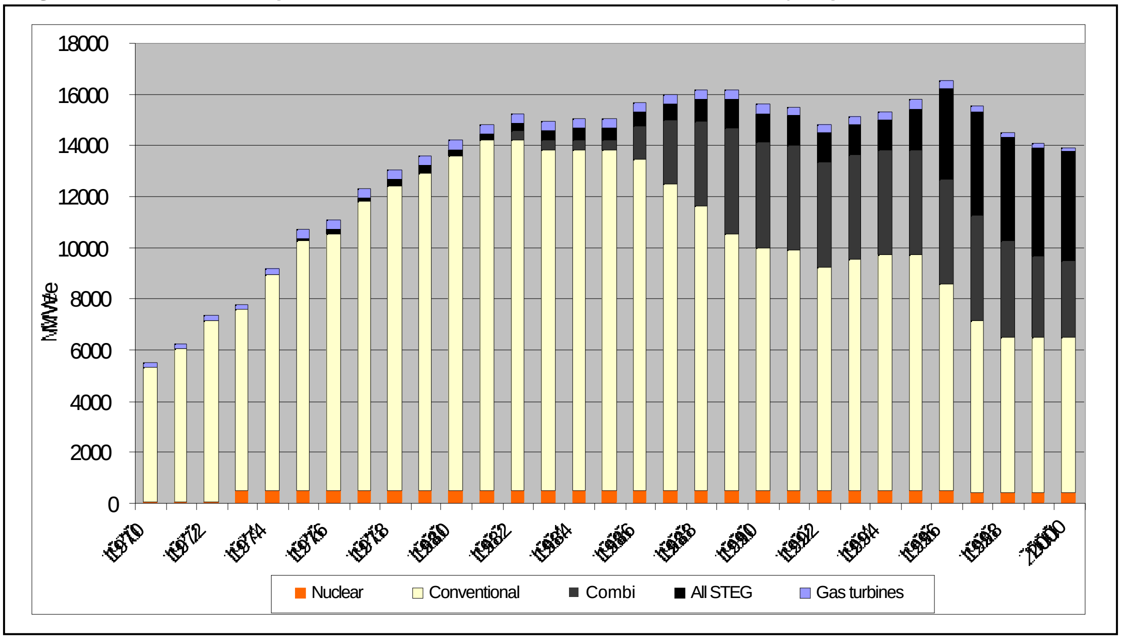
- The gas turbine perfectly served a market niche, peak shaving, which improved overall efficiency of the system of generation and distribution;
- The development of gas turbine technology was mainly spurred by its application in jet engines, this created learning effects, proved the potential of the technology and its reliability, thus turning it into a proven technology the end of the sixties;
- Knowledge regarding gas turbine technology had several similar features to steam turbine technology and alliances between companies involved electricity generation and aircraft firms were formed
- Spin-off of military R&D was significant, gas turbine producers for electricity generation were able to appropriate these learning effects.

After its introduction in the electricity sector the gas turbine developed from very specific applications to a general accepted part of electricity generation. Various companies searched for opportunities to apply the gas turbine also in the base load area of centralised electricity generation. Islas (1997: 64) summarises the development process:

> "The emergence of the gas turbine from the electrical peak demand niche into the electrical semi-base and base took place when certain very specific electricity company projects encouraged hybridisation between the steam turbine and the gas turbine, and where the gas turbine functioned as an auxiliary device in the operational plan of the steam turbine, thus leading to combined cycles operating with high load factors. The adaptation of the gas turbine to a new operational system of longer duration, "learning by using", and the speed of the technical progress of the gas turbine, all led, especially when the technical progress of the steam turbine started to stagnate, to restructuring of the combined cycle, in which the gas turbine finally became the principal component".

Electricity companies increasingly acknowledged the importance of combined cycles. Manufacturing companies, such as General Electric, Westinghouse, Kraftwerk Union, and Brown Boveri all implemented development and marketing programmes for combined cycles. Between 1960 and 1974, 17 combined cycles came into operation with electricity companies in Europe and in the middle of the seventies "*combined cycle gas turbines displayed techno-economic characteristics which revolutionary in comparison with the steam turbine*" (Islas 1997). These involved thermodynamic efficiencies up to 45%, construction times two to three year less than for large conventional power stations, investments per MW installed 30% lower than for a large conventional power stations, low operating and maintenance costs, and good environmental performance relative to conventional power plants (Islas, 1997). Dutch manufacturing and electricity companies were not involved in the development of the combined cycle. Early activities of the electricity sector involved assessment of the applicability of the combined gas turbine (VDEN, 1980). After the oil crisis ideas of energy saving and improvement of efficiency became more prominent in the dominant regime. The uptake of combined cycles fitted well into the concepts of energy saving and increasing efficiency. The combi power plant could be built from existing steam turbine driven power plants. Pre-connection of gas turbines in front of steam turbines led to improvements of total capacity and efficiency of power plants. An advantage of the combined cycle was its applicability to existing plants fired with other fuels than natural gas. Later the STEG configuration that could only operate on natural gas came in operation. Availability of natural gas facilitated the application and diffusion of gas turbine technology in the Netherlands but the penetration of combined cycles and STEG was mainly influenced by Dutch resources strategy varying from strategic depletion of natural gas reserves to renewed attention for coal in order to diversify the use of resources. Only after the policy of prudent use of gas laid down in the energy note of 1979 and the focus on re-introduction of coal was dropped penetration of combined cycles really took off from the middle of the eighties on. Figure 1, shows how gas turbines, combis, and STEG, slowly penetrated the electricity regime.

Figure 1 Penetration of gasturbines in the steam turbine based electricity regime in the Netherlands



Sources: SEP, EnergieNed, CBS, Elan.

The penetration of hybrid forms of gas and steam turbines did not change the basic technological configuration of the electricity system as a whole: centralised, large-scale, fossil-based electricity generation, with high voltage transport and low voltage distribution to customers. However an additional characteristic of combined cycles were the opportunities for application of heat. This was particularly interesting in the light of energy saving policies and government actively stimulated heat distribution projects. The electricity industry was less enthusiastic regarding heat distribution, among others because it reduces electrical efficiency and because it implied large investments in terms of heat infrastructure[3], but was pressured by government to develop this new technological path. Due to irreversibilities in infrastructure (cumulated investments in long distance electricity transport could not be combined with heat distribution) and lay out (central power plants were located far from sources for heat demand), and lack of experience, central CHP projects were not successful. Naturally, also an extensive gas distribution network had already evolved in the Netherlands as the principal source for heat demand. Historically, these systems have evolved in competition, making co-operation and integration virtually impossible (Verbong, 2000).

In conclusion, the introduction of the gas turbine and hybrid forms of gas and steam turbines opened up opportunities to shape ideas of energy saving, but also opened up opportunities to introduce more efficient combined heat and power production. The electricity industry was more or less forced to broaden their task of electricity producer towards the distribution of heat, due to general climate towards energy saving and government pressure. Whereas the electricity industry was not very inclined to engage in heat production and distribution it did broaden the traditional electricity focus of the dominant regime and opened up the regime towards taken into account issues such as energy saving and environmental impacts of electricity production.

3.3. Competing designs in the electricity regime from the end of the eighties

Gas turbine technology also played a pivotal role in the hollowing out of the centralised electricity regime. It was able to deliver high electric efficiencies at smaller capacities, and industries increasingly used gas turbines from the seventies on to shave peak demand and serve base loads, as well as to produce combined heat and power. When institutional change opened up the previously closed actor network of the electricity regime, the strategies of distributors converged with those of industrial actors and decentral combined heat and power production boomed. Centralised electricity generation was at its peak in the sixties of seventies when the share of private, decentral production of electricity reached historical low levels of 19 % in 1968 and 10 % in 1978 (Blok, 1993). The search for higher efficiency and energy saving measures initiated by the two oil crises however strengthened the interest in combined heat and power generation. After the oil crises CHP was the only available short-term alternative to save energy. Combined with a number of factors this led to an uptake of decentral electricity production from the end of the 1980s on, and decentral electricity production increased from 15 % in 1988 to 22% in 1994 and 31

[3]In central CHP the heat produced by large scale power generation is distributed to significant sources of heat demand, such as housing districts, horticulture. Tapping the heat leads to some loss of electrical efficiency of the power plants.

% in 1997 (Arentsen et al, 2000). Several factors explain the fast expansion of decentral CHP:

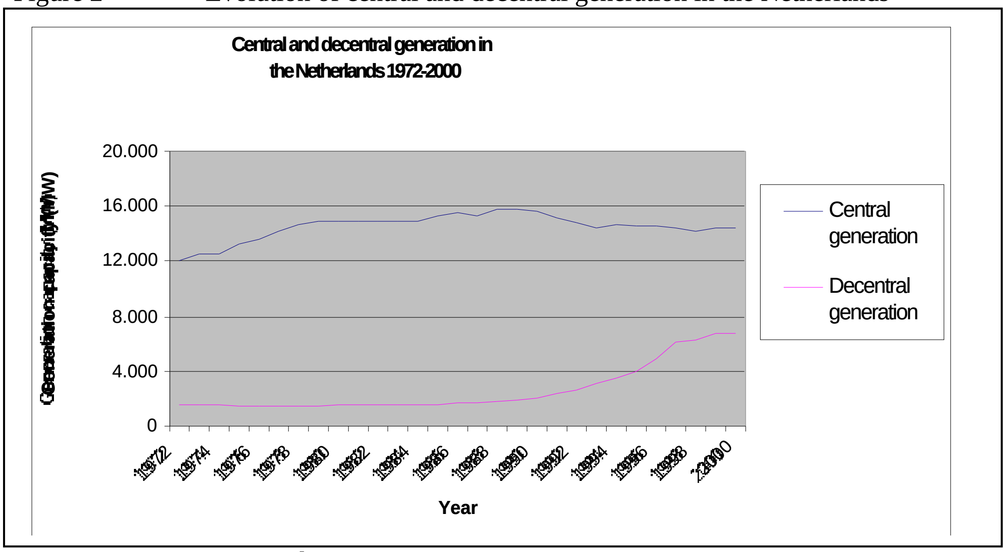
- Gasturbine technology had become efficient and available for medium size CHP capacities[4];
- Legal opportunities to produce decentral CHP were expanded;
- Distributing companies engaged strongly in decentral CHP as a means to compete with the central producers, also by creating coalitions with industrial companies to get around the installed capacity limit of 25 MW;
- Both economic incentives (investment subsidies and beneficial gas tariffs for CHP-appliances) and adaptations (in various steps) in remuneration tariffs encouraged decentral CHP;
- The obligation for distributors to purchase surplus electricity delivered to the grid by decentral CHP installations for a reasonable price;
- Both industry and the distributors committed to specific environmental targets regarding energy efficiency and CO_2 reduction through voluntary agreements with government, CHP was a major instrument to reach targets agreed in the covenants;
- The development of a policy package to stimulate CHP (investments subsidies, fiscal measures, attractive gas tariffs and remuneration tariffs) in combination with the set up of a specific CHP-office (PWK) that supported and promoted these measures, thus streamlining the multitude of programs, subsidies and tax measures.

Thus, a combination of factors and measures led to a boom in decentral CHP basically because it became economically attractive for various companies and organisations to invest in CHP equipment. What is especially of our concern is that previously accepted principles and established actor constellations were being challenged. The question of ‘what led actors, and government specifically to advance decentral CHP with so much rigour at that time?’ is crucial because this period visibly marks the beginning of corrosion of the belief in the centralised mode of electricity production. It also marks a change of the previously more or less closed arena of decision making on electricity production and planning towards a more open and differentiated arena. In the ‘tension’ between centralised and decentralised electricity production, apparent in the electricity system from its outset, the strong belief in superiority of centralised electricity production weakened. Two actor groups were increasingly challenging this superiority. In the first place industry, and especially those industries engaged in electricity generation for in-house use, organised through the Vereniging Krachtwerktuigen. Already in the fifties VKW argued that combined heat and power production could reach efficiencies up to 70 %. The general opinion of public electricity producers was voiced by director Vos[5] of the energy company of Amsterdam: “*in the same way as the freight horse carrier has lost its battle to the truck, small scale self generation can not compete with large scale generation anymore*”. Also due to efforts of VKW, self-producers in industry became more organised[6] and increasingly were recognised as a significant industrial interest group[7].

The emergence of natural gas and the development of gas turbine technology increased opportunities for industrial CHP. Secondly, government actors increasingly challenged the efficiency of centralised electricity production. There was growing consensus that the monopolistic organisation of electricity production and distribution facilitated inefficiency and slack[8], and that government needed to increase control over electricity planning. Also, there was a growing belief that combined heat and power generation could realise substantial energy saving. Early efforts concentrated on implementation of central CHP through large distant heating projects, but were not very successful.

During the eighties it became increasingly clear that combined heat and power production could be much better realised with decentral applications. Decentral CHP was much more flexible and could be tuned to heat demand sources, for example through systems of various sizes in industry. With electricity prices at high levels in the beginning of the eighties, and industry effectively lobbying for measures to increase facilities for decentral power generation, the Dutch government initiated a comprehensive policy package to stimulate decentral CHP. Moreover, the electricity act facilitated new actor constellations, especially coalitions between industry and distributing companies, thus enabling effective application of decentral CHP. The sharp increase in decentral CHP from the end of the eighties on is shown in figure 2.

Figure 2 Evolution of central and decentral generation in the Netherlands



Sources: ECN, EnergieNed, CBS.

[4]In the small capacity range the use of gas engines was common.
[5]L. Vos in 1951 (Binnen paal en perk, overdruk uit Electrotechniek van 20-12-1951) quoted by Buiter & Hesselmans (1999: 96), translated from Dutch.
[6]For example, in 1957 VKW became member of FIPACE, the international organisation of industrial electricity producers. FIPACE was established in 1954 by West European industries because of commercial barriers enacted by monopolistic suppliers of electricity (Buiter & Hesselmans, 1999).
[7]This is illustrated by the emergence of natural gas in the Netherlands in the beginning of the sixties. From the outset VKW was an official party in negotiations regarding supply contracts with giant users. According to Buiter and Hesselmans (1999: 101) this can partly be explained by the fact that only Gasunie was party in the supply of gas, whereas in the case of electricity there were various suppliers.
[8]This was a perception that was gaining ground internationally, leading to a wave of liberalisation and privatisation in various countries. Among the first countries to privatise public owned energy companies were Chile and the UK. The relative success of these experiences led other countries to follow (Gilbert and Kahn, 1996; Patterson, 1999).

Summarising, the boom of decentral produced heat and power in the early nineties marks a number of fundamental changes in the electricity system. Above all, the principles of central station electricity and monopolistic (public) organisation were corroding. Central station electricity had always been the basic organising principle for generating and distributing electricity. Introducing the production of heat as one of the determinant organising factor implied a change in form and function. Specifications of power plants were now also determined by the heat load it has to meet, something for which decentral CHP was much better suited (Patterson, 1999). The organisation of the electricity system was turned upside down by the Electricity Act in 1989, which separated production from distribution. In the previous homogeneous and closed decision making arena of the electricity sector a new atmosphere emerged. Whereas previously electricity companies had closed their ranks vis a vis the outside world, from then on especially distribution companies were seeking ways to compete with the production companies.

In overview in the period 1970-2000 corrosion of the strength of the regime took place through a number of factors:

- Gas turbine technology, and its hybrid forms with steam turbine technology, in its early adoption phase strengthened the regime because it could satisfy demands for energy saving and efficiency. Later its development towards smaller scale increasingly challenged the guiding principles of the central station electricity system;
- Institutional change has opened up the closure and centrality of the dominant regime;
- Developments in cogeneration technology in combination with opportunities due to institutional changes and policy stimulation packages increased the scope for decentral production.
- The dominant regime faced increasing difficulty in meeting external demands that developed from environmental concerns with regard to emissions, to efficiency concerns, and to climate change concerns.

Figure 3 gives a simplified representation of the development of the electricity regime. From the seventies on the regime has gradually become less stable. Although the central station electricity system is still dominant, an increasingly varied mix of other options for electricity generation now accompanies it. The next paragraph analyses how flux in the electricity regime has opened up opportunities for a variety of actors.

Figure 3 Overview of developments in the electricity regime 1970-2000

		1973	1979	1989	1998
Degree of regime stability	Very stable	Stable	Less stable	Less stable	Flux
Technologies	Steam turbine	Steam turbine, gas turbine (niche)	Hybrid steam turbine (STEG) / gas turbine	Niches - Decentral CHP - PV - Wind - Biomass	Increasing variety of niches - renewables - green electricity - fuel cells, microturbines
Technological configuration	Stable	Stable	Adapted with STEG	Attacked by decentral CHP	Central station electricity model shifts to EU level
Degree of external demands	Low	Emerging availability, environmental concern, fuel diversification	Efficiency, Environmental concern	Efficiency, Climate change concern	EU free market; NL efficiency, climate change
Market organisation	Monopoly	Monopoly	Monopoly	Towards free market	Free market
Organisation of actors	Stable	Stable	Concentration (national)	Concentration and division (national)	From public to private owned; from national to foreign ownership; new actors; new coalitions
Entrance to regime	Closed	Closed	Closed	Limited access	From limited to free access

4. Change in the electricity regime: new actors, coalitions, concepts and niches and the role of policy

For more than a half century the electricity regime was rather stable, as a closed and stable network of actors had been able to control both the direction and speed of change in electricity generation, transmission and distribution, based on steady growth of electricity consumption. In a process of decades the stable electricity regime developed towards flux. Its social network became unstable as national government aimed to exercise more control, and industrial and societal actors challenged guiding principles of the regime. The regime was long able to deal with increasing external demands such as efficiency and environmental emissions without fundamentally changing the sociotechnical configuration. The separation of electricity production and distribution companies in 1989 however led to increasing tension within the social network of regime actors. New coalitions were formed between electricity distributors and industrial actors for decentral cogeneration of heat and power at the expense of central electricity generation. The over capacity that followed was already a sign of the loss of control by regime actors. The anticipation of further liberalisation and the increasing importance of the climate problem led also to new actor coalitions that developed and marketed the novel concept of green electricity. The phased introduction of free choice of electricity provider for consumers led to the end of fixed price developments based on the natural monopoly model. With the emergence of new markets, exchanges and actors old social networks vanished and new networks emerged. With the landscape development of liberalisation, climate change and information technology increasingly penetrating the electricity regime, uncertainty over the future direction and speed of developments in electricity generation and use became high. Networks of actors are involved in different development paths and it is difficult to predict which group will become dominant. An example of the strategy of a new and powerful entrant in electricity generation is illuminating. Shell is investing significantly in networks and R&D for the development of hydrogen production, storage and fuel cells, photovoltaic systems and offshore wind farms. Its investments in gas, production fields, pipelines and liquid transport, is even higher. Thus, it is playing the game of being party in all the potential energy sources and technologies that may determine the direction of future energy systems. The next section focus on what role policy played in the electricity regime and how it can play a role in initiating transition paths.

Energy policy: from diversification to energy saving to climate policy

Climate policy emerged as a separate policy field in the course of the nineties. Before that, policies related to climate change were initiated through diversification policy (after the oil crisis), energy conservation policy, and environmental policy. These changes also signify changes in expectations regarding the course of the energy system. Diversification and conservation originate from concern regarding the availability of fossil fuel resources, while environmental policy initially dealt with some of the unwanted side effects of fossil fired power plants. These policies all have different connotations regarding the role of renewable energy, but most importantly they did not fundamentally challenge the basic configuration of the energy system. In diversification policy, renewable energy was seen as one of the several options for relieving the dependency on oil. Rather quickly however, diversification policy became set on a course towards three pillars for the energy system: one-third coal-fired plants, one-third nuclear energy plants, and one-third gas fired plants. Alternative renewable energy options became labelled as: not mature, not reliable, not a good fit for the central station electricity system, and were not seriously considered as an alternative, also because the problem could be solved in another manner. Later, efficiency became the major ideograph, not necessitating a fundamental questioning of the configuration of the energy system, or the serious consideration of alternatives. Efficiency could also become part of the macro-agenda because it did not challenge the much more vigorous ideographs of economic growth and technical progress. Actually, efficiency could be associated with technical progress, and, especially in the circles of Economic Affairs, growth was seen as a means or even precondition to enable efficiency gains. When in the course of the nineties climate change concerns started to enter the agenda one of its effects was that it reinforced the belief in the need for efficiency improvement. Consequently, in current policies to reduce CO_2 emissions the use of policy instruments that aim at efficiency improvement is dominant, and efficiency gains are expected to realise a significant part of the emission reduction. The introduction of target group policy at the end of the eighties, the conclusion of several voluntary agreements, also on energy efficiency, and the use of various generic fiscal instruments all breathed the dominant focus on efficiency improvement. Priority number one for energy R&D in the nineties was energy saving. However, in the last one to two decades efficiency gains have been more than offset by economic growth, thus effectively leading to an absolute increase of emissions of CO_2.

Retrospectively then, climate related policies have until the end of the nineties a dominant orientation towards optimisation of the current electricity system. Policies initiated out of diversification and efficiency concerns have been extended. The focus of climate related policies was on the dominant actors in the electricity system, but did not fundamentally change the agenda and expectations of the sector. While the gas turbine initially served a niche within the system and fitted the agenda of efficiency improvement, wind energy was dropped in the electricity system without sufficient attention for a process of niche development by creating some protected space for its development, and with a too limited process of agenda building and shaping realistic expectations, thus reinforcing the sector's negative expectations regarding the potential of wind energy. Experience with wind energy in the seventies and eighties shows a mismatch between government policies and the dynamics of sociotechnical change. In the nineties, with the changing mode of governance, dynamics of technological development for wind energy changed (also because with the environmental action plan and the introduction of the MAP levy a successful match between actor strategies and policy strategies emerged), and another mismatch between the government approach and government tools became apparent. One mismatch was the strong focus on setting a target for wind energy implementation at the national level without including local actors in this process of agenda building. A second mismatch was the inability to integrate climate related policies, and especially wind energy policy, with policies regarding spatial planning and procedures regarding decision making for wind sites.

The most successful government interventions occurred when the mode of governance had its first turning point with the separation of producers and distributors. The policy package for cogeneration in combination with catalysing efforts through the set up of a project office, and more attractive remuneration tariffs for surplus electricity, led to a sharp increase in cogeneration power plants. With the relative high electricity prices and low gas prices industrial actors seized the opportunities that were previously both legally and financially unattractive. Technological development towards more efficient small scale gas turbines, the changing mode of governance, and the focus on the possibilities in industries for combined use of heat and power, initiated fundamental changes in the electricity system. Although in the beginning of 2000 the climate for cogeneration has significantly deteriorated due to lower electricity prices, higher gas prices, and less government incentives, technological development towards more efficient small scale systems is still ongoing at the international level.

Institutional change led also to stronger market orientation of the energy distribution sector and partly explains the emergence of the concept of 'green' electricity. In this case the government policy of greening the tax system, and especially the regulatory energy tax and the exemption for green electricity, turned a to be a major incentive for customers to buy green electricity, especially when the energy distribution sector engaged in coalitions with environmental NGO's. This illustrates the importance of (changes in) actor strategies, their relation to modes of governance, and the potential of well timed incentives to create momentum.

In overview, climate policies have long embarked on increasing efficiency to reduce CO_2 emissions. Renewable energy was long assessed on its ability to become part of the existing electricity system. In recent years, the sense of urgency regarding the climate problem has increased, and also the belief that the electricity system has to change in a more fundamental way. The introduction of policy instruments that put a cap on CO_2 emissions, e.g. emission trading, is now articulated by a number of actors.

Energy oriented technology policy

Whereas climate policy has been more focussed on stimulating actors to select more efficient and climate friendly technologies, energy oriented technology policy is focussed on developing various energy technologies that are more inherently climate friendly. Efforts in the seventies and eighties have been mainly of a technology-push nature, and although being effective to some extent to generate variety in terms of technological development paths, these policies have been less successful in creating coalitions of actors that could engage in actual experiments and an interactive learning process. Especially in its R&D strategies the dominant orientation of government has been top-down, single-actor and single technology oriented. While this has been successful to some extent in improving environmental performance of the fossil-based regime, multi-actor and multi-level strategies (systems change strategies) are more likely to craft paths out of the current carbon lock-in. Especially the integration of promising technologies into a fitting system of electricity generation, distribution and use has been difficult. One of the causes is rather restricted and deterministic analytical framework underlying R&D strategies. Especially the analysis of innovation dynamics in society turns out to be restricted, since the analysis concentrates on relieving barriers for innovative decision making of individual actors and the emergence of desired technologies, without sufficiently taking into account the interrelatedness between technologies, infrastructure requirements and the lumpiness of energy sector investments. This requires technological change of a systemic nature, implying complex relationships between different types of technology providers, infrastructure firms and users. Incentives need to steer the creativity of key economic and social actors and guide the learning processes within and between firms, e.g. through client-supplier relationships (Martin, 1996). R&D strategies have been focussed on a economical and technological dimension, and not sufficiently on the societal dimension with interaction between technology push and market pull, processes of network building on the local level, learning processes, and experiments between various actor groups are important mechanisms. Priorities within government R&D have shifted from nuclear energy and coal energy to energy conservation and renewable energy, but the fixation on single technologies and actors is still dominant. Developing a much more systems oriented R&D strategy is one key to generate more effective integration of technologies in the system of electricity generation, distribution and use.

Retrospectively, we conclude that intentional government steering has been relatively unsuccessful in the cases for which government had very ambitious goals, such as for nuclear energy and wind energy. Yet, while R&D strategies have not been very effective in embedding technological development in society, they have played a crucial role in maintaining and keeping open technological variations for electricity generation.

5. Towards transformation of the electricity regime?

Although it is uncertain how the design of electricity generation and use will develop and which energy technology will become dominant it is possible to discern a number of trends that impact these developments. Some of these may provide the seeds for wider transformation of the electricity regime towards sustainability. They also provide starting points for climate policy. These trends are the following:

1. There is increasing heterogeneity of actors involved in electricity supply and interactions of actors with different backgrounds. This is related to changes in market structures, e.g. new exchanges and the emergence of trading companies; in regulation due to the removal of entrance barriers; and to converging strategies of actors from different regimes, e.g. waste regime and its focus on closing material cycles and reduction of waste landfill and the use of the energy contents of (organic) waste for electricity generation.

2. There is a trend towards more segmentation of electricity based on economic aspects, market aspects, and societal aspects. Economic aspects relate to price differentiation for electricity in periods of peak demand, and off-peak demand, and different contracts that are being settled between producers and customers. Market aspects relate to specific requirements of electricity users, such as a level of reliability that is higher than average. Societal aspects relate to the differentiation of electricity to energy source or production location, such as the demand for green electricity, or domestic green electricity, or electricity not produced by nuclear power.

3. There is a trend of emergence of new services related to energy. For example, actors mediating for collective purchase of electricity for a variety of consumers. Or the provision of a package of electricity, water and telecommunications under one administrative umbrella, or the provision of smart metering systems and software to reduce energy use and costs.

4. Increasing concentration and internationalisation of traditional producers of bulk power. The previous mainly domestic oriented electricity supply industry developed a more international orientation as a wave of liberalisation in electricity markets swept the world. Restructuring, competition and regulatory reform broke down traditional boundaries between electricity, fuel, and equipment suppliers. A growing number of mergers and joint ventures emerged at the turn of the century involving electricity utilities, gas utilities, gas pipelines and gas marketeers. In the Netherlands, for example, foreign electricity companies were able to enter the market through acquisition of until then monopolistically organised domestic electricity producers.

5. Electricity became an international traded commodity instead of a nationally produced public good. International transport of electricity rose as significant price differences existed between countries and providers. With the majority of Dutch park of power plants based on natural gas[9] and its price increasing in the second half of the 1990s, electricity from coal-fired and nuclear power plants in other countries could often be contracted at a cheaper rate. Imports of electricity rose to 30% of total electricity use and the import capacity of the grid was constraining further growth. This also led to problems at the infrastructure level as border capacity was limited because grids had been designed to provide back-up support for the monopolistic organised domestic electricity regimes, and not to facilitate massive power flows that could result from free trade.

[9] In 2000 more around 80% of central installed power plant capacity used gas as a fuel. For decentral power plants the figure was even higher.

6. Electricity is changing from an invisible public good that is provided at the socket in your home to a visible marketable product. Thus the importance of marketing of electricity is becoming more and more important. This is also related to possibility for consumers to choose their own provider and product, and thus consumers established their own contracts with electricity providers. The role of marketing has become crucial in strategies of energy providers, and several new companies have been able to gain market share by making use of advanced marketing techniques.

7. The continued importance of the climate change problem and the increasing translation into regulations that internalise the carbon costs of electricity generation. An example is the regulatory energy tax in the Netherlands, and the increasing basis for a EU carbon tax, and the start of pilots for carbon trading and planning of a carbon trading system for Europe.

8. The process towards the use of more flexible electricity generation systems. This is flexibility in terms of shorter construction periods, ability to use power plants both for peak and base-load production, or as a back-up system, and a more modular character of energy technologies.

9. The increasing importance of gas as a source for electricity generation. The combined cycle gas turbine has become the most efficient means of electricity generation, while also being flexible in terms of scale. In Europe investments in power plants were stagnating due to over capacity, and the only plans in relative large scale power plants were in CCGTs, such as Shell’s construction of a CCGT 600 MW power plant in the Botlek area for combined production of heat and power. In the US major investments in new power plants were planned at the turn of the century to satisfy demand and to replace obsolete power plants. Around 90% of these investments were expected to be in gas-fired power plants (combined cycles and gas turbines) because of their flexibility and relative low capital costs (to coal-fired and nuclear power plants).

10. A trend of increasing venture capital for alternative energy technologies such as fuel cells and offshore wind farms. Increasingly are willing to invest in these funds because of high expectations for energy technologies that are flexible, modular and have low environmental impact.

11. The trend towards a changing role of consumers from passive consumer to more active. Investments in renewable sources such as wind and biomass were especially driven by the emergence of green electricity, in which consumers specifically chose for electricity produced by renewable sources.

12. An increasing variety of technological and market niches for electricity generation and use based on several of the aforementioned trends. A patchwork of niches is in development in order to exploit the opportunities of the enlisted regime changes. There is a large variety of options for electricity generation available and in development. Examples are different types of fuel cells, microturbines, hybrid microturbines/fuel cells, tidal/wave technologies, biomass conversion technologies, pv technologies, wind turbine types, etc. With the increase of pressures on fossil based electricity generation in the past decades the diversity of

these options has steadily grown. Liberalisation of electricity markets has provided another incentive to the development of alternatives to centralised large-scale fossil-based electricity generation.

Some of the recommendations for **climate policy** are mainly concerned with supporting the flux in the electricity regime so as to initiate and facilitate possible pathways to the transition to a carbon-lean energy supply. It was noted that energy technology policy is too unilaterally concerned with encouraging individual energy technologies and too little with technological hybridisation and the social and organisational milieu within which technology operates. Local experiments in particular could offer a counterweight to too close a focus and emphasis on large-scale wind and biomass projects. Such local initiative fit in well with the increasing differentiation in user preferences, levels of reliability and service packages. While alternative technologies, such as microsystems, fuel cells, solar energy, small wind turbines and biogas installations still cannot compete with large-scale, centrally generated electricity, they are nevertheless capable of further development because they link up better with certain elements of differentiation. Examples are the greater reliability of fuel cells, which is becoming increasing important in financial transactions; avoiding the problem of locally overburdened networks, mainly by IT companies using microsystems; closing feedback loops by using manure to produce biogas; and profiting by the increasing user preference for green electricity from small-scale solar and wind energy. These sorts of initiatives give alternatives the opportunity to improve and in the long term increase the potential for further reduction of CO2 emissions.

6. Conclusion

This paper has analysed the past three decades in the electricity system from the perspective of sociotechnical change. The main finding is that the electricity regime that was previously stable is now in a state of flux, represented by tensions in the development of various elements (both social and technological) in the regime. The paper has listed several trends based on these tensions that potentially have significant impact on the further development path of the electricity regime. A main point is that these developments are all the result of actor networks and their strategies. As the outcomes of these developments are not yet fixed, are impacted by contingencies, and in some cases yet need to materialise, they offer leads for policies towards sustainability, while transition theory can provide insight in how regime transformation can take place.

References

Arentsen, M.J. and J.W. Eberg (2001) *Management of Technology Responses to the Climate Change Challenge,* Dutch National Research Programme on Global Air Pollution and Climate Change, Bilthoven, 2001.

Arentsen M.J., P.S. Hofman, N.E. Marquart (2000) *Development of CHP in the Netherlands, 1974-1998,* CSTM, Enschede.

Arthur, W.B. (1988) Competing technologies: an overview, in Dosi et al. *Technical Change and Economic Theory*, London, Pinter Publishers.

Bijker, W.E, T.P. Hughes and T. Pinch eds. (1987) *The Social Construction of Technological Systems*, Cambridge: MIT Press.

Bijker, W.E. and J. Law (1992) *Shaping Technology/Building Society, Studies in Sociotechnical Change*, Cambridge: MIT Press.

Blok, K. (1993) The development of industrial CHP in the Netherlands, *Energy policy*, February 1993, pp. 158 – 175.

Hirsh, R.F. (1999) *Power Loss: The Origins of Deregulation and Restructuring in the American Utility System*, MIT Press, Cambridge.

Hofman, P.S. and N.E. Marquart (2001)*'Electricity in Flux, Sociotechnical Change in the Electricity System, 1970-2000'*, Dutch National Research Programme on Global Air Pollution and Climate Change, Report no. 410 200 073, Bilthoven.

Hughes T.P. (1983) *Networks of Power*, John Hopkins University Press, Baltimore.

Patterson, W. (1999) *Transforming Electricity, The Coming Generation of Change*, Earthscan, London.

Pinch, T.J. and W.E. Bijker (1987) The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other, in *The Social Construction of Technological Systems* W.E. Bijker, T.P. Hughes and T. Pinch eds. 17-50, Cambridge: MIT Press.

Rip, A. and R. Kemp (1998) Technologic Change, Chapter 6 in S. Rayner and E.L. Malone, *Human choice and climate change*, Volume Two, Resources and Technology, pp. 327-399, Batelle Press, Columbus.

Verbong G.P.J. (red.), Energie, in: Schot, J. et al, *Techniek in Nederland in de Twintigste Eeuw, II, Delfstoffen, Energie, Chemie*, Stichting Historie der Techniek, Walburg Pers, Zutphen, 2000.

Weaver, P., L. Jansen, G. van Grootveld, E. van Spiegel and P. Vergragt (2000) *Sustainable Technology Development*, Sheffield: Greenleaf Publishing.

Williams, R. and D. Edge (1996) The Social Shaping of Technology, *Research Policy*, 25, 865-899.