Innovation and Institutional Change

The transition to a sustainable electricity system

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INNOVATION
AND INSTITUTIONAL CHANGE

THE TRANSITION TO A SUSTAINABLE ELECTRICITY SYSTEM

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Preface

This dissertation on systems change in the electricity system has its roots in various research projects on which I worked in the past years. My interest in change processes was especially triggered when I was involved in the evaluation of pollution projects in the Province of North-Holland. It resulted in various publications, together with Theo de Bruijn, on the role of pollution prevention in changing behavior of business and in realising more far-reaching environmental innovations. At that time I also started to become active within the Greening of Industry Network, also facilitated by Theo as GIN coordinator. The work on the review article for the GIN conference in Rome, which I wrote together with Ed Stafford and Cathy Hartman, broadened my understanding of the type of change processes necessary to move forward towards sustainable development. It especially made clear to me how such processes can only succeed through mobilisation and partnering of a range of actors that bring in different ideas and resources. A more specific focus on system innovation in the energy sector originated through my participation in the research project 'Management of Technology Responses to the Climate Challenge', coordinated by Maarten Arentsen. I had extensive discussions with my roommate Edwin Marquart on developments in the electricity system. For the report we wrote together, Edwin was also mainly responsible for the data and figures, and some of these data are also recurring in this dissertation. I thank Edwin for his contribution to this thesis and also for the good times we had in discussing all kinds of energy and societal issues. In the project I was also introduced into the sociotechnical system perspective. Especially working together with Arie Rip and Rene Kemp proved to be very instructive. Later on I worked together with Boelie Elzen and Frank Geels on designing sociotechnical scenarios for the electricity system, who I thank both for this productive collaboration. This work is extended in a current project where together with Geert Verbong, Rob Raven and Boelie Elzen further exploration of energy transitions takes place. Especially Geert, with his extensive knowledge of and insightful books on the energy system, has given useful advice for which I thank him.

This dissertation was facilitated by many at CSTM. In the first place I want to thank my promotor Hans Bressers who has given practical advice on how to deliver this dissertation within the set time schedule and who was always supportive and positive. I also want to thank Maarten Arentsen who stimulated me in the initial stages to develop a plan for the dissertation and who provided support from CSTM together with Hans. The support of Bill Lafferty is also gratefully acknowledged. Bill has given useful comments on several occassions and also asked me to contribute to the Condecol project at ProSus, through which I was able to gain more insight in the complexity of innovation journeys. I also thank Audun Ruud, Olav Mosvold-Larsen and Rolf Marstrander with whom I collaborate within the Condecol project. I especially want to thank Ada Krooshoop who played an important role in reminding me about the deadlines within the process of delivering the dissertation and for her editorial work. I want to thank all my colleagues at CSTM for the good work atmosphere and their support.

This dissertation is about path dependence in many ways. From a personal perspective academic thinking has been strongly rooted within my family. It is likely to be unique to be fifth in line within one family achieving such a milestone. I am proud to be part of such a family, and also want to express my immense gratitude to my father and mother who have worked very hard to make all this possible for their children. We tend to take it for granted but it takes strong and special characters to raise a family of eight and to give them so much opportunities to develop themselves. Finally I want to thank the person who has given me the motivation and strength to finish this project. Although it has been difficult for Mai and our son in accepting the long work hours, her support and the joie de vivre of our son Sam have been, apart from scientific curiosity, main drivers for this book.

Peter Hofman, Enschede, October 2005.

Chapter 1

Transition to a sustainable electricity system

Introduction and research questions

1.1 Introduction[1]

Electricity has become taken for granted in industrialised societies. Like water and food it is now regarded as a basic necessity expected to be available at all times. The benefits of electricity are well known: it is a resource indispensable for manufacturing the products we consume, and it is a resource essential for the functioning of a wide range of products, such as household and office appliances and appliances related to entertainment and communication. The creation of these benefits has however come at significant cost. Industrialised societies, and especially energy and transport systems, are addicted to fossil fuels. The emergence and shape of these systems is inextricably linked to the exploitation of fossil resources such as coal, oil and gas. Apart from local and regional environmental problems, carbon emissions through fossil fuel burning have created the problem of human-induced global warming[2]. The nature of this global warming problem is unprecedented: it threatens fundamental aspects of ecosystems and society in decades to come[3]. The required response will be unprecedented as well: one element is that it demands fundamental transformation of existing

1 The finalisation of this dissertation has taken place under the umbrella of a research project 'Transitions and transition paths' funded by the energy research programme of the Dutch Scientific Council and Novem. Support is gratefully acknowledged. Further support was given by a research grant under the programme Innovation and Governance of the Institute for Governance Studies of the University Twente and is gratefully acknowledged.

2 Global warming is in itself not a new phenomenon as Earth's climate history shows cycles of warming and cooling, to a significant extent associated with natural variations in CO_2 concentration in the atmosphere. However the current rate and speed of change in CO_2 concentration is generally accepted as unprecedented and generated by human activities (IPPC, 2001).

3 The lag of the effects showing themselves is one aspect of the complex nature of the problem: humans tend to fix problems once these have surfaced; in this case we have to prevent or reduce the effects from occurring although we do not yet see and understand the problem fully. This has led to the formulation of the so-called precautionary principle.

systems of production and consumption away from its carbon base; another element is that it demands alternative forms of governance stretching from the local to the global.

Shaping of both elements as a response to the climate change challenge has been taking place for some two decades now but results in terms of reduction of greenhouse gases and realisation of effective modes of governance are disappointing[4]. Some reduction in carbon intensity may be observed, mainly because of a shift from coal to gas and increasing energy efficiency, but these tend to be offset by increasing energy consumption triggered by rising mobility and new electricity consuming ICT applications, among others. Successes in switching to alternative energy and transport systems are incidental, isolated and emerge too slow to make a real impact in expanding economies. For global governance, ratification and entry into force of the Kyoto Protocol in 2005 may be considered a relative success that is seriously diminished by the withdrawal to the climate treaty of the USA, the major contributing developed country, and Australia. Despite potential free-riders, the European Union and individual countries such as the Netherlands, remain committed to the Kyoto Protocol and the climate policy process. The results in the Netherlands have been poor however. CO_2 emissions increased with 12% from 1990 to 2003 (RIVM, 2005a: xxi). Increases in the energy and transport sector have been especially rapid with 36% and 26% respectively, while the industry sector realised a reduction in CO_2 emissions of 12% from 1990 to 2003 (RIVM, 2005a: xxi). Due to a drop in CH_4 emissions, N_2O emissions, and F emissions (HFCs, PFCs) overall greenhouse gases increased by 1.5% in the period 1990-2003, well off the target of a reduction of 6% of greenhouse gas emission in 2008-2012 relative to 1990 (RIVM, 2005a: xi, 1-3). Nevertheless, it is expected that with a stabilisation of greenhouse gas emissions in the Netherlands for the reference period, the Kyoto target can be realised with emission reduction realised outside the Netherlands (RIVM, 2005b: 13).

These data illustrate typical characteristics of the response to the climate change challenge. A first element is that the restructuring until now has mainly taken place by eco-efficiency strategies of industries, mostly through incremental innovations that optimise existing industrial production, and that the underlying carbon base has not really changed. A second element is that the formation and negotiation of a global institutional arrangement for the climate problem takes place through a sequence of small steps (Hasselmann, et al. 2003). The focus has foremost been on realising initial short-term reduction targets, implying that the interim targets of the Kyoto Protocol

4 See for example Van Ierland et al. (2003) for an overview of main issues, complexities, controversies and implementation aspects in international climate policy.

may well be realised. Yet, the real challenge lies in realising the reductions of 50% up to 80% in 2050 that are necessary to curb human-induced climate change. Discussions regarding the type of strategies necessary to realise these far-reaching reductions can be connected to similar debates regarding strategies for a sustainable development. A major issue has been whether more ‘incremental’ eco-efficiency strategies will be able to deliver, whether more radical technological changes are required, whether we need more fundamental changes in social and institutional frameworks, or whether a symbiosis between these is possible. This issue is also of central concern to this book, which focuses on the electricity sector as a key system in the change towards a carbon-lean and sustainable society. The next section introduces main lines in this debate and also focuses on the challenge of transforming the electricity system, and this is followed by a clarification of the plan of the book.

1.2 What path to sustainability[5]?

The concept of sustainability has come to occupy a permanent place on the public agenda (Hajer, 1995). On the one hand, the academic community, governments, businesses, and broader society recognise sustainability’s importance for the future health and welfare of the planet and its inhabitants. On the other hand, an accepted definition of sustainability continues to be elusive. The most familiar definition comes from the 1987 Brundtland Commission Report entitled, Our Common Future, which describes sustainability as development that “*meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987: 43). Since that publication, dozens of new interpretations and working definitions of sustainable development have appeared (e.g. Lélé, 1991; Brooks, 1992), sparking debate over what sustainability really means and how to realise it.

Over the past decades, a variety of paradigms for enacting sustainability have emerged. For example, several authors argue that eco-efficiency provides an important path to global sustainable development (e.g., Schmidheiny, 1992; Von Weizsäcker et al., 1997). In their view, market signals (e.g., tax incentives, tradable pollution credits, eco-certifications) should be refashioned to reflect the environmental costs of production, resource use, recycling, and disposal. Ecological modernisation provides a similar perspective as it “*assumes that existing political, economic and social institutions can internalise the care for the environment*” (Hajer,

5 Parts from this section are based on Hartman, Hofman and Stafford (1999) and (2002).

1995: 25). A basic tenet of ecological modernisation is "*that the capitalist political economy needs conscious reconfiguring and far-sighted action so that economic development and environmental protection can proceed hand-in-hand and reinforce one another*" (Dryzek, 1997: 143). Ecological modernisation theory advances the idea that collaboration of key actors such as government, industry, reform-oriented environmentalists, and science, can generate win-win outcomes of economic development and environmental improvement[6]. These paradigms suggest that sustainability is possible via more sensible and innovative uses of resources through a process of continuous, incremental improvement.

Others point out that higher efficiency will not be enough. It may slow down the rates of contamination and depletion, but does not stop these processes (McDonough and Braungart, 1998). Moreover, eco-efficiency does not pay attention to social dimensions of sustainability (for instance inter- and intra-generational equity). This leads to a plea for more structural changes. The second perspective therefore can be called 'systems change'. Several approaches can be identified with different accents on how this change process may come about and who will be the main actors driving the process.

The *engineering* approach to systems change stresses fundamental changes in design parameters, principles and requirements that are necessary. McDonough and Braungart (1998, 2002) argue for a 'next industrial revolution', a completely different way of designing industrial production[7]. Instead of becoming more efficient they argue for new design principles that eliminate dangerous emissions altogether and adopt concepts such as 'waste equals food' and 'cradle-to-cradle'. An example is the elimination of 7,962 chemicals used in the textile industry for carpet production on a total of 8,000. The fabric was to decompose naturally and effluents of the manufacturing process were as clean as the influents[8] (McDonough and Braungart, 1998). Parts of products composed of materials that do not biodegrade should be kept at a minimum and be designed as technical nutrients that circulate within closed-loop industrial cycles ('cradle-to-cradle'). Related ideas are those of biomimicry (Benyus, 1997), natural

6 Note however that scholars such as Spaargaren (2000) and Huber (2000) reject reducing ecological modernisation to a simple efficiency approach, and explore how more structural changes may come about.

7 The next industrial revolution will in their perspective built on three basic concerns: equity, economy and ecology which they have developed into a design tool called the Triple Top Line (McDonough and Braungart, 2002).

8 The carpet was not sold as a product but provided customers with the service of the carpet while still owning the material (Presentation at GIN Conference, Chapel Hill, USA, 1999, and McDonough and Braungart, 1998).

capitalism (Hawken et al., 1999), and industrial ecology (Graedel and Allenby, 1995). The approaches are convincing in providing an alternative to the existing exploitive nature of industrial systems, and especially in pointing out how this alternative will imply a fundamentally different design of industrial production. A main weakness is the lack of explanation how these alternative design principles can take root and establish themselves at the expense of or in symbiosis with existing design practices. A second weakness is that the social and institutional dimension of applying these design principles is hardly addressed, whereas application of these principles will require new sets of organisational and institutional arrangements, and also different routines and habits at the level of households, consumers, and citizens. The inherent sustainability logic of the concepts and the design principles put forward have triggered more recent work, however, to develop further ideas on how the concept of industrial ecology can be integrated in policy and management (e.g. Korhonen et al., 2004).

The *business* approach assigns a central role to firms taking principles of sustainability aboard and assumes diffusion to take place once the competitiveness of such a strategy becomes established. Superior performance of stocks on the Dow Jones Sustainability Index and the competitive edge of companies that adopt a sustainability strategy to work with and engage stakeholders such as employees, communities, citizens, governments and (prospective) consumers are seen as central elements for firms' continuity (Hart, 1995; 1999). Global sustainability is pictured as the unfolding source for creative destruction (Hart and Milstein, 1999), and serving the world's poor is seen as the future source of growth and profits for multinational companies (Prahalad and Lieberthal, 1998; Prahalad and Hammond, 2002). Others criticise the view of multinational companies leading the transformation to sustainability. For example, Welford (1998) asserts that the present structure of capitalism has contributed significantly to environmental degradation and to the increases of inequity and inequality. Thus, only new modes of social organisation and market structures using appropriate technologies and values can enhance the overall quality of life. Since traditional business systems are responsible for many of today's social and environmental problems, new ways to move forward must be found (Welford, 1998).

The *cultural or value-oriented* approach puts less faith in business leading towards sustainability but points at the importance of changing the underlying values, conventions and practices in social systems. Placing ecological values at par or above material values and emphasis on the intergenerational aspects of sustainability are two elements. A basic interpretation is that values within the era of mass consumption have become detached from nature. On the one hand we may appreciate and value nature, and be a member of nature conservation groups, on the other hand we may travel across the globe to consume and enjoy unspoilt nature. Changing behavioural patterns, lifestyles, and associated values then form a crucial part of systems change (Spaargaren et al., 2002). Moving toward sustainability is not just about fulfilling existing needs more efficiently, it involves also changing these needs and the way these are socially embedded (Shove, 2004). Understanding how these behavioural patterns are embedded in specific modes of provision and systems of production may provide clues for this (Van Vliet, 2002; Spaargaren, 2000).

The *technological* approach assigns a central role to technological change in systems change to sustainability. Developing and diffusing new technologies with radically better performance is the main challenge. For example, Grübler et al. (1999) identify technological change as a major driving force in the decarbonisation of the global energy system. Improved performance and reduced costs are seen as the major factor for new energy technologies replacing old ones (Grübler et al., 1999). The focus on technological solutions has also a strong footing in Dutch policy approaches towards solving major environmental and energy problems (VROM, 1993, 1996; Arentsen and Hofman, 1996; Hofman, 1997; Hofman and Marquart, 2001). Broadening the focus on technical and economic aspects with a focus on social aspects of technological change has taken place from 1990 on, as the Dutch Commission for Long-Term Environmental Policy concluded that conventional innovation processes could not deliver the large environmental gains necessary for sustainable development. What was required were innovation processes designed from a long-term time perspective, with sustainability considerations incorporated from the onset, and understood as co-evolution of social and technological change (Weaver et al., 2000; Hofman and Schrama, 2003). This can be seen as a precursor to the current ‘transition approach’ which seeks, in time frames up to fifty years, fundamental shifts in the way particular functions (energy, transport, agriculture) in society are fulfilled (Rotmans et al., 2000; VROM, 2001).

The *governance* approach focuses on the nature of institutional arrangements that may hamper, facilitate and/or lead the process towards sustainable development. Hardin’s (1968) ‘tragedy of the commons’ can serve as a classic example of this approach with the tragedy being that individuals maximizing their utilities may cause overexploitation of freely accessible resources. In response, numerous cases of successful long-term local self-governance of common property resources have been identified (Ostrom, 1990). However, the effectiveness of arrangements may erode due to social, economic and technological developments[9] and the associated reduction in social capital[10] (Pretty and Ward, 2001). Thus, it can be concluded that effective institutional arrangements need to be able to adapt to changing conditions and circumstances, or in other words successful commons governance require that rules (co-)evolve (Dietz et al., 2003: 1908). Moreover, in complex systems such as the electricity system there are different sets and layers of institutional arrangements at work. This involves for example economic relations where market arrangements through prices and contracts play a central role, relations regarding knowledge and R&D where network relations and trust may play a more important role, and grid operation where with more hierarchical relations and rules regarding access and use. The development and implementation of the Kyoto-protocol involves then a new institutional arrangement directly influencing activities of actors within the electricity system and indirectly through influence on other institutional arrangements. Important aspects to take into account are whether some sort of order exists between these arrangements and how this order evolves; and the way these arrangements may work out differently at local, regional, national, and international scales. This had led some to point out some potential conflicts between different institutional arrangements, e.g. Jörgensen (2005) argues how the recent shift to market models for electricity in Denmark has induced abandonment of national support schemes for renewable energy and is at odds with the public commitment to a sustainable energy system. In a more fundamental focus on governance for sustainable development, Lafferty (1998, 2001) identifies mismatches between existing decision-making procedures in democratic market economies and the type of institutional arrangements reconcilable with sustainable development. Lafferty argues that a strengthening of regional ecological community building needs to complement and counteract political and economic globalization.

The main purpose of this overview is to make clear the range of different positions in the way sustainable development may be achieved. Our concern is not to choose a particular approach but more how useful elements of the approaches can be combined. The main proposition we start from is that it will be essential to bring various elements together, and create alignment and

9 For example, the traditional muang-fai system of irrigation was designed by local communities in the North of Thailand and has long been successful in managing the allocation of water. However, many muang-fai organisations disintegrated under the pressure of rapid economic and social change (industrialisation and globalisation) and were unable to manage the rising conflicts over water provoked by growing demand, the rising number of consumers, and new power relations (Hofman, 1998a: 290-291).

10 The term social capital "*captures the idea that social bonds and social norms are an important part of the basis for sustainable livelihoods*" (Pretty and Ward, 2001: 210).

specific momentum for processes towards systems change and sustainable development. Central is further the recognition that the nature of changes necessary in the pursuit of a sustainable electricity system demand new paths that involve co-evolution of innovation and institutional change. Understanding the nature of this co-evolution is a first objective of this dissertation. Analysing how this co-evolution has shaped the way certain paths have unfolded for electricity production and consumption is a second objective. The final objective is to utilise these insights to provoke, redirect or reinforce more sustainable patterns of co-evolution.

1.3 Research questions and outline of the chapters

Central to this book is the understanding that transformation of systems of production and consumption involves a process of co-evolution of institutional and technological change and involves changes in institutions at different levels and between those levels. At the micro level it involves the development of a new product, technology or concept, made possible as a variety of actors, such as firms, policy-makers, customers, change their way of doing things. At the meso-level it involves changes in practices at the level of sectors, and at the macro-level it involves changes in systems of innovation and regulation. Systems change slowly occurs as changes at different levels start to connect and synchronise, leading to the emergence of new institutional fabric that creates linkages between the different levels.

The aim of this book is to specify this perspective by analysing patterns of change in the electricity system. Scientifically, the relevance of the book is in its analysis and explanation of fundamental processes of change, a topic relevant for a range of scientific disciplines, from economics, sociology, technology studies, to policy science. Its societal relevance lies mainly in its use for gaining insight in the way systems change can be directed towards the normative goal of sustainable development.

The overall research questions by which this research is guided are:

To what extent can the dynamics of transformation in the electricity system be understood as the interaction between technological and institutional change?, applied more specifically to:

a. how does this dynamics take place at and between different levels?;
b. when and how does this dynamics reinforce the existing system, representing processes of lock-in, or destabilise the existing system, representing processes of escaping lock-in?; and,

c. how can these insights be utilised to direct systems change in a more sustainable direction?

The following chapters provide the answers to these research questions.

Chapter two presents an overview of theoretical work relevant to the study of systems change and focuses on the way different theoretical streams deal with the institutional factor in fundamental changes of production and consumption systems (in short: systems change).

Chapter three builds upon the theoretical reflections of the previous chapter and develops an analytical framework that structures the empirical part of the book. Main elements of the conceptual model used in the empirical chapters are introduced and explained.

Chapter four – stability and transformation in the electricity system – analyses main changes that have taken place in the electricity system in the past three decades. The initial focus is on explaining the emergence of a range of alternative paths within the electricity system, varying from nuclear technology, to wind energy, biomass, cogeneration, and green electricity. Next the focus is on explaining relative success and failure of the paths taken within the context of the electricity and broader institutional arrangements for knowledge generation, economic exchange, policy and regulation, societal legitimacy. In-depth review of two relative successful paths takes place in two further chapters.

Chapter five – the evolution of decentral cogeneration – provides insight in how changes in the institutional setting, in connection with some other changes, can trigger a process of change where a previously disfavoured technological concept and design becomes more and more attractive and fundamentally alters basic beliefs and principles underlying the system.

Chapter six – the emergence of green electricity – provides a more detailed assessment how the introduction of a new concept within the electricity system triggers changing interactions between institutional change at different levels which may offset a process of systems change.

Chapter seven extends the analysis of past changes in the electricity system and utilise the insights for the development of potential transition paths towards a more sustainable electricity system. In a first step the focus is on methodological aspects of the development of transition paths. Two scenarios are constructed based on this methodology to illustrate potential transition paths. This is followed by policy recommendations drawn on the basis of these scenarios.

Chapter eight summarises the main findings of this book and the answers to the research questions. It also focuses on the lessons that can be drawn for actors to direct the dynamics in the electricity system towards more sustainable paths.

Chapter 2

Theoretical perspectives

2.1 Introduction

The objective of this dissertation is to analyse developments in the electricity system in order to understand their potential contribution to fundamental change in the electricity system. In order to be able to assess the nature of changes in the electricity system and their driving forces, a first analytical step is to gain more insight in processes of systems change based on theoretical observations from other scholars. Therefore this chapter presents an overview of theoretical work relevant to the study of systems change and focuses on the way different theoretical streams deal with the institutional factor in fundamental changes of production and consumption systems (in short: systems change). The chapter is guided by the following research question:

How do existing theories understand processes of systems change, the interaction of technological and institutional change within these processes, and the factors that explain whether these interactions reinforce or weaken the existing system?

The issue is how to analyse fundamental changes in complex systems of production and consumption consisting of a range of actors, linkages and components. Our main premise is that fundamental change in a system of production and consumption such as the electricity system involves several change processes that occur both simultaneous and sequential, and at different levels of firms, users, sectors, governance systems, systems of innovation and society at large. The main challenge is to increase understanding in how change processes interlock and acquire a certain velocity and direction (or momentum as Hughes (1983) would say) towards an alternative or new sociotechnical configuration. A further challenge is to gain understanding whether, when, where and how sustainability can be successfully incorporated into those change processes. The purpose is to derive some general principles based on theoretical and empirical work of other scholars, and in combination with insights drawn from own work develop a conceptual framework that will guide the empirical chapters that focus on dynamics in the electricity system.

Our approach is the following: first we introduce the work of early scholars on principal elements and mechanisms in systems change: innovations, institutions and their interaction. Next we outline more recent theories relevant for the study of systems change: sociotechnical change theories such as the large technical systems approach, evolutionary theories such as the national systems of innovation approach, governance theories, and institutional theories such as the new insitutionalism in organisational analysis and ecological modernisation. A further section summarises theoretical and empirical contributions to overall patterns of breakthrough innovations and systems change. In 2.4 insights of various scholars are integrated into a conceptual perspective for the analysis of systems change. A final section summarises the most relevant findings.

2.2 Broader theories on social and economic change

Economists' starting points

Innovations are regular phenomena in our society and often considered as a crucial element for societal progress in the long run. Yet there is widespread disagreement on the reasons why they come into being, on what explains the nature of innovations, and on the ways through which they affect societal progress, although quite a number of scholars have made impressive efforts in this respect (among them Smith, 1776; Marx, 1890; Schumpeter, 1928, 1947; Nelson and Winter, 1982; Dosi et al., 1988; North, 1990; Freeman and Soete, 1997; Freeman and Louca, 2001). Common for them is how they point at the interaction of innovations and institutions as the fundamental force for economic growth. This is implicit in the work of Smith as he describes the shift from craftsmanship to a factory mode of production and explains how mechanisation combined with a new division of labour dramatically raised productivity (Smith, 1776; see also Landes, 1969 and Freeman and Louca, 2001). Thus innovation went hand in hand with change in forms of organisation and coordination, two principal elements of institutional arrangements. Marx (1890) points at further institutional facets such as the importance of property in terms of money and how this affects labour and capital accumulation, and the way capital gained primacy over labour as labour price becomes disengaged from value creation. His focus was on the way capitalist institutions bring forth technical change (especially labour-saving) and capital accumulation. The importance can hardly be overestimated: it is a particular institutional set-up that creates incentives to generate innovation and utilise science for that goal, and to expand production scales, markets and products (Rosenberg, 1994: 88-97). Schumpeter explicitly points at innovations as the prime drivers of economic development. He defines innovation as the carrying out of new combinations, through "*the doing of new things or the doing of things that are already being done in a new way*" (Schumpeter, 1928: 377-378; 1947: 151). He emphasised the radical nature of innovation in the sense that such innovations trigger processes of creative destruction, making existing firms and economic structures obsolete: "*the new processes do not, and generally cannot, evolve out of the old firms, but place themselves side by side with them and attack them"* (Schumpeter, 1928: 384). Schumpeter makes a distinction between the managerial and the entrepreneurial function, with the former focussed on optimising routine work in a stable configuration and the latter keen on new possibilities and getting new things done as they "*are able to cope with the resistance and difficulties which action always meets outside the ruts of established practice*" (Schumpeter, 1947: 152). Entrepreneurship is central in his understanding of economic evolution, with the successful creation of a 'new combination' leading to large gains, triggering imitation by others, and involving clustering of innovations that disturbs ways of doing things and equilibrium throughout the economy. Schumpeter pointed at the interaction of institutional forms with entrepreneurial activity as he identified a shift from an entrepreneurial regime, with innovations primarily associated with the entry of new firms, towards a 'routinised regime', with increasing routinisation of innovation within R&D departments of larger firms (Schumpeter, 1947; terminology from Ruttan, 2001: 106). Schumpeter predicted the end of capitalism (and creative destruction) and the formation of a whole new social structure because of the loss of the entrepreneurial class in the routinised regime but underestimated ways in which systems change may come about (Schumpeter, 1947: 158). Schumpeter has been rather influential in setting the agenda towards research on the nature of innovation and the innovation process, the way radical innovations emerge and diffuse (endogenously) and undermine stability in the economic system, and the way clusters of innovations evoke structural economic change.

Sociologists' starting points

To understand change of systems in production and consumption the view on innovations and the behaviour of producers and users needs to be complemented by an understanding of how such a system is on the one hand embedded in broader processes of societal change and on the other hand emerges because of changes in human behaviour, interaction and practice. Max Weber conceptualises this with the building blocks 'social action' and 'order'. Action is behaviour invested with meaning, and the prefix social implies action is oriented to another actor[1] (Smelser and Swedberg, 2005: 9). Order comes into being "*when social actions are repeated over a period, regarded as objective, and surrounded by various sanctions*" (Smelser and Swedberg, 2005: 9). In his classical 'The Protestant Ethic and the Spirit of Capitalism', Weber pointed at the link between patterns of behaviour ingrained by Protestantism and the advance of modern Western industrial economy (Landes, 1969: 22-23; Castells, 1996: 210-215). The relevance lies in the general argument that cultural and institutional transformation brought forth a new paradigm of economic organisation and the necessary ethical foundation for pure individual profit-seeking (Castells, 1996: 211, 213). Also Beck (1992: 201) points out that Weber argued that "*work, technological change and economic development are tied into the system of cultural norms, the prevailing expectations and the value orientations of people*". Sociologists also criticise basic premises regarding rational behaviour of actors utilised in mainstream economics. Simon stressed the bounded rationality of human behaviour due to limits of individual cognitive capacity and March and Simon argue how an individuals' actions are strongly conditioned by the organisation which they are a part of (Scott, 2001: 26). Parsons (1982) explained how systems of norms regulate the interaction of humans, and Berger and Luckmann (1966) focus more on cognitive aspects and argue that reality is a product of social interaction based on the formation of shared knowledge and belief systems which guide human behaviour. More broadly speaking, the notion of institutions is used to capture the way human behaviour and interaction is enabled, guided, constrained and regulated by various types of rules (Scott, 2001). Institutions have taken a central place in a variety of approaches from different academic disciplines. Consequently, there is a wide divergence of definitions regarding institutions and in ways to study them. Table 2.1 introduces three main pillars in the nature of institutions, based on Scott (2001). The regulative pillar is broadly accepted: institutions regulate and constrain behaviour. Economists predominantly draw on this pillar in the way they integrate institutions into economic reasoning (e.g. Williamson, 1981 and North, 1990). In the normative pillar behaviour is conditioned by social beliefs and norms. Early sociologists such as Parsons and Durkheim see institutions as resting mainly on this pillar (Scott, 2001: 55-56). The cognitive pillar of

[1] With the focus on individual action and its relation to other actors Weber distinguishes himself from micro-economics where individual action is seen as unconnected to other individuals (Smelser and Swedberg, 2005: 4).

institutions focuses on the way shared conceptions regarding reality emerge and the way things are done becomes taken for granted (Scott, 2001: 57-58).

Table 2.1 Three pillars of institutions (adapted from Scott, 2001: 52)

	Regulative	Normative	Cognitive
Dominant mechanism	Authoritative, coercive (threat of sanction)	Normative (threat of exclusion from social group)	Mimetic, shared strategies, interpretations (habits and routines as carriers) (lack of alternative)
Basis of compliance	Expedience	Social obligation	Taken-for-grantedness, shared understanding
Examples	Formal rules, laws, standards, sanctions, incentive structures	Values, norms, responsibilities, codes of conduct	Mental models, evaluation routines, dominant design principles, problem agendas, beliefs, paradigms
Main institution-making mechanisms	Formal bodies, such as government agencies, industrial-standard setting bodies	Processes of formal and informal network and actor group formation (social capital)	Fora and arenas where ideas and experiences are exchanged
Logic	Instrumentality	Appropriateness, being part of the group	Orthodoxy
Basis of legitimacy	Legally sanctioned	Morally governed (trust)	Culturally supported, frames of reference

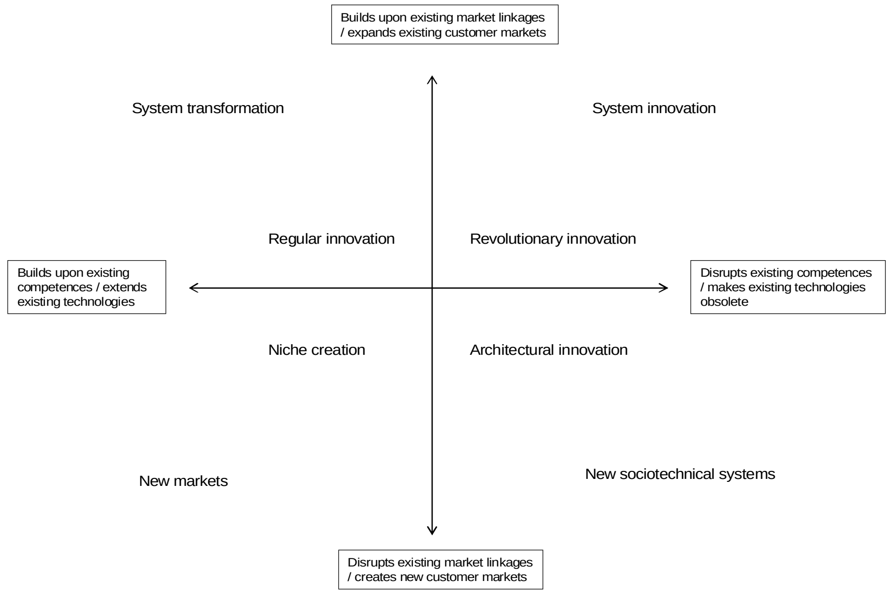
2.3 How do innovations and institutional change contribute to systems change?

2.3.1 The nature of innovation, the innovative process and its contribution to systems change

A commonly used definition of innovation is by Rogers (1995: 11): "*An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption*". Although innovations are introduced regularly within organisations, firms, industries and society, only some innovations initiate or form a crucial part of a process of systems change. A starting point for this chapter is to learn more about what characteristics of innovations and which nature of the innovation process provide seeds for systems change.

Typologies of innovations have been developed by various scholars to discern between types of innovations varying from more incremental to radical innovations. As radical innovations imply a break with many of the ways things were done in the past, they are often associated with systems change. In the innovation typology by Abernathy and Clark (1985: 5) the most radical innovations are those that make existing technologies obsolete and disrupt existing market linkages, and they labelled these architectural innovations, see the inner typology in the quadrants in Figure 2.1. This is contrasted with regular or incremental innovations that build upon existing competencies and linkages. If the nature of innovations is connected with the nature of systems change, a typology such as in the outer part of the quadrants in Figure 2.1 can be drawn. Although useful, this two-dimensional typology is too limited and does not take into account other relevant types of changes involved in systems change, such as in networks, institutions and the way the system is embedded in society.

Figure 2.1 Typology of innovation and systems change (adapted from Abernathy and Clark, 1985: 8)



Based on the model in Figure 2.1 the development and diffusion of radical innovations fundamentally changes or replaces existing systems. To induce radical innovations the previous dominance of theories based on a linear model of innovation led to a strong focus on science-driven and supply-push policies, as discoveries in basic science would precede inventions in applied science, and end with innovation and its diffusion (Freeman, 1996: 27). This dominance was also explained by the fact that at that time science had played an important role in the development of nuclear power while various innovations took place that were expected to lead to the use of nuclear power as a cheap and abundant energy source. In the last decades, however, the importance of demand-pull (market-driven) and systems oriented theories of innovation have gained ground (Von Hippel, 1988; Lundvall, 1992; Nelson, 1993). This has led to a more balanced understanding of innovation where both the science and knowledge base and the market are seen as important factors in innovation processes. Moreover, the sequential nature of the innovation process was seen as unsatisfactory, for example Rosenberg (1982) shows that once a technology has reached the market place ongoing innovation still is an important factor for improved performance. Through learning by using the cumulative impact of small improvements can lead to significant increases in productivity, such as in the case of electricity generation where the fuel economy of centralised thermal power plants improved from using seven pounds of coal to generate one kilowatt-hour in 1900 to less than 0.9 pound of coal in the 1960s (Rosenberg, 1982: 65). Also Enos (1958) finds for petroleum refining that improving a process contributes even more to technological progress than does its initial development (in Rosenberg, 1982: 68). Processes of learning by doing and learning by using are therefore crucial.

Innovation is not necessarily equated with change of a single technology. Rosenberg (1982) points at the role of complementarities: a particular technology can move forward because of inventions and improvements in other technologies. Thus it may be fruitful to think of major clustering of innovation from a systems perspective, such as has been the case in the building of systems for electricity and lighting where a variety of innovations played a role in making a working configuration, apart from someone like Edison who combined innovations from a systems perspective (Hughes, 1983). The result is that improvements in performance in one technology will be of limited significance unless it is paralleled by improvements in other parts or technologies (Rosenberg, 1982: 60).

A further insight is that the focus need not necessarily be on the level of technology or system of technologies but more broadly on actors, networks and institutions. For example, Berkhout et al. (2002: 19) conclude in research of the European pulp and paper and PVC producing sectors that "*orders of magnitude improvements were achieved through the accumulation of product and process changes over time, … while much of the explanation for these changes can be found in the steady reconfiguration of actors, networks and institutions*" in and around these industries. Thus, systems change cannot simply be equated with technological changes. Let us consider for example the way the system of food system has changed by focusing on the production and consumption of milk. Fifty years ago milk production was close to an artisanal profession and consumers could almost point out the cow they drank the milk from. Nowadays we have multinational producers of dairy products, ranging from conventional milk to drink yoghurts to exotic drinks, making use of large-scale standardized production processes, and with consumers buying the products in a variety of outlets. Cows produce an average of eighteen liters of milk per day compared to around eleven liters fifty years ago in a highly mechanized way and in large-scale facilities (Bieleman, 2000: 152). Although the whole system of milk production and consumption has dramatically changed in almost every aspect, and this has involved dramatic changes in ways of production, transportation and linkages to customers, it is generally not perceived as systems change.

This leads to the conclusion that although a division between incremental and radical innovation is conceptually clear, the connection to systems change is more problematic. It also implies that a strict division between incremental and radical innovation is not fruitful in the analysis of systems change. Understanding interactions between and changes within actors, networks and institutions and the way these produce and affect processes of innovation and possibly result in systems change is the basis of our approach.

Our focus in this chapter is on the reasons why new ideas, concepts or objects (for example technologies or new forms of organisation) emerge, and under which circumstances they provide seeds for more fundamental changes in systems. First we discuss several theoretical streams in the literature that have been particularly concerned with these issues starting from an economic and/or technological perspective.

Evolutionary economics

Applying evolutionary principles and the central importance of innovation in the economic process, in the seventies and eighties several scholars point at the cumulative nature of innovation and the selective nature of the innovation process (Nelson and Winter, 1977, 1982; Dosi, 1982, 1988; Freeman et al., 1982; Rosenberg, 1982). The basic ideas in evolutionary economics are inspired by evolutionary theories in biology (see Van der Steen, 1999; Ehrlich, 2000) and use the concepts of variation, selection and evolution to explain economic development. The concept of variation is in biology associated with genes in organisms, which are fundamental to behaviour and are passed on from one generation to another. The selection environment, and changes within this environment, determines the type of genes that will survive. An evolutionary path is created through changes in the pool of genes, either by spontaneous mutation or by pressure of the selection environment.

Nelson and Winter (1982) developed an evolutionary theory of economic change with routines as principal elements to explain firm behaviour. In evolutionary economics, habits and routines function as relatively durable genes, because "*firms may be expected to behave in the future according to the routines they have employed in the past*" (Nelson and Winter, 1982: 134). Routines are defined as decision-rules that are applied routinely over longer periods of time, and "*range from well-specified technical routines for producing things, procedures for hiring and firing, ordering new inventory, or stepping up production of items in high demand, to policies regarding investment, research and development, or advertising, and business strategies about product diversification and overseas investments*" (Nelson and Winter, 1982: 14). Routines are 'remembered' by doing, just as professional piano- or tennis-players need to practice every day to keep their movements smooth and accurate, in a natural and unconscious way. This also implies that there is some level of tacitness involved: routines can not be transferred smoothly, just as skills need to be built up. Nelson and Winter (1982: 16-17) discern three types of routines within firms, those of an operational nature, those regarding investment decisions, and routines to modify various operating characteristics, thus contemplating whether the way they are doing things is still appropriate. Here they assume a hierarchy of decision rules with higher order procedures governing modification of lower ones. In the economy the most successful routines survive (are selected) and are transferred to other firms through imitation, take-overs, labour mobility and training. According to Nelson and Winter routines also play a crucial role in innovative activities. They view innovations in organisational routines as new combinations of existing routines. They argue that problem-solving is routinised in terms of the way the problem is approached: certain search and problem-solving heuristics are applied (Nelson and Winter, 1982: 132-133). Search processes are local in the sense that the focus is on techniques close to the current one (Nelson and Winter, 1982: 211). This leads to technological trajectories based on general principles on how to move a certain technology, technological configuration or system forward. Saviotti (1996: 45) argues that "*know-how, routines, decision rules and dominant competences are relatively invariant with respect to many types of environmental changes thus giving rise to dominant designs, technological regimes and paradigms*". Dosi (1988: 225) uses the term technological paradigm that defines "*the technological opportunities for further innovations and some basic procedures on how to exploit them*". Certain exemplars (basic artefacts such as a car, steam turbine or fuel cell) are further developed and improved on the basis of a set of heuristics that guide direction and knowledge nature of search processes (Dosi, 1988: 224). An example is the steam turbine for which efficiency steadily improved by increasing scale and realising higher temperature and pressure (Hirsh, 1999: 56; Verbong, 2000: 226; Hofman and Marquart, 2001: 43).

What is less clear in the work of Nelson, Winter and Dosi is how paradigms emerge or how shifts from one paradigm to another occur, and the nature and effects of embeddedness of these paradigms outside the realms of firms and engineers. The role of external changes will play an important role as is argued by Saviotti (1996: 45-46): "*However, important environmental changes requiring, for example, substantial modifications of the technologies used by a firm, are likely to induce changes in routines, know-how and competences which are then transmitted to subsequent generations*". What remains unclear, however, is to which external changes routines and know-how of a firm remain relatively invariant and to which not. A second more fundamental criticism is that these scholars model the selection environment as a (set of) factor(s) independent to the agents that generate variation. Especially more sociological interpretations of technological changes point at continuous interaction between the selection environment and variation and argue that the way these are shaped and take on certain more structural forms is essential. Van den Belt and Rip (1987), in their analysis of the synthetic dye industry, argue that the "*influence on the selection environment often results in a nexus, that is a social institution that carries and shapes the interaction between trajectory and selection environment*". This implies a shift from a focus on evolution to co-evolution: understanding the way particular technological paths are embedded in, and co-evolve with, broader institutional structures.

Evolution of large technical systems

This approach is especially relevant for the analysis of the electrity system as a system of technologies in which infrastructure plays a central role. Of crucial concern is the work of Thomas Hughes, who interpreted the electricity system as a seamless web of interwoven elements of both a technical and non-technical nature (Hughes, 1983; 1987). His analysis thus focuses not on individual technologies but on the way the development of a variety of elements tends to reinforce the system as a whole, involving clusters of technologies and knowledge generation, and creating some specific dynamics as general understanding is created as to how to further optimise and expand the system. This takes the form of engineering guiding principles such as how increasing scale of steam turbines is accompanied by higher efficiency, and by fine-tuning of the system with public policy, such as through the establishment of monopoly as the natural form of organisation[2]. This yields to, what Hughes referred to as, momentum of the technological system, a certain orientation of technological and social developments that fosters further growth of the system. Aspects such as sunk costs, fixed assets and vested interests also add to system momentum (Hughes, 1987: 77). An example of an orientation contributing to momentum in the electricity system has been the search for ways to increase the load factor of the system[3] through the shaping of societal demand for electricity in off-peak periods[4]. Crucial for the continuous expansion of large technical systems is how efforts are collectively mobilised to overcome reverse salients: critical problems for the further development of the system. In Hughes' analysis especially the role of system builders is crucial in the articulation of these critical problems and in the alignment of actors in the process of solving the reverse salients. The focus was also on the way the system was shaped by social forces, such as through the acceptance of monopoly organisation as a natural organisational form for electricity systems. Cultural and institutional differences also explain the divergence in electricity systems across nations despite the application of similar technologies, or in Hughes' words: "*technical problems are sometimes in essence institutional and value conflicts*" (Hughes, 1983: 462). The analysis of Hughes shows how activities in different dimensions (politics, technology, industry) became directed towards further expansion and optimization of the electricity system, but also how differences in societal contexts (USA, UK, and Germany) shaped patterns of interaction between those dimensions and led to rather diverse systems.

Following Hughes' approach, a stream of work focusing on large technical systems has emerged that shares the focus on the way social and technical elements are interwoven and actors are guided by principles that shape a certain stability of the system (Mayntz and Hughes, 1988; Summerton, 1994). In this more recent work Hughes' focus on understanding system momentum and stability is increasingly complemented by a focus on understanding processes of reconfiguration and change in large technical systems. One of the key aspects is how "*previously achieved closure is undone*" (Summerton, 1994: 5). Closure refers to dominance of a specific interpretation about the way a system should function, leading to disregard

2 Hirsh (1999) analyses how consensus regarding utility organisation was established in the United States in the early twentieth century, and how corrosion of this consensus took place from the 1970s onward.

3 Load factor refers to the rate of utilised capacity of the electricity generating units in the system. The load factor initially was rather low, as electricity demand tended to cluster around certain periods (peaks) and was much lower in other periods.

4 Nye (1990) provides an elaborate and interesting account of this process of electrification in the early stages of the electricity system in the United States.

of alternative views of outsiders. "*Closure in technology involves the stabilization of an artifact and the 'disappearance' of problems*" (Pinch and Bijker, 1987: 44). It refers to actors developing belief systems that are aligned to the components, principles and design of the technological system. Examples are the belief that the electricity system is a case of natural monopoly, and the belief that central electricity generation is superior to decentral forms of generation (Hirsh, 1999; Verbong, 2000; Hofman and Marquart, 2001).

Strong points of the large technical system approach are the way it is able to unravel core coordinating mechanisms and guiding principles within emerging systems and the way their emergence and application co-evolved with political and institutional processes. Hughes' focus is however foremost on the way large technical systems expand and gain momentum, and much less on the way systems may be fundamentally changed, transformed, or replaced.

National systems of innovation approach

The large technical systems approach focuses more on interaction processes within technological systems than on broader processes of societal and institutional change that influence and interact with patterns of change in technical systems. The national systems of innovation (NSI) approach is more concerned with the way specific institutional set-ups influence patterns of innovation throughout the economy. As interactive learning is perceived as crucial in innovative processes one of the foci to what extent the institutional set-up facilitates this, especially through processes where interaction between various actors is essential to realise exchange, transfer and use of knowledge (Freeman, 1987; Lundvall, 1988; 1992, 2002; Nelson, 1993). Freeman pointed out the importance of institutional factors in his study of Japan as a then fast rising industrial power, and stressed the importance of the strong government-business relationships and of managerial and organisational forms such as the just-in-time concept (Freeman, 1987). Crucial for the success of Japan's economic growth has been the ability to organise, mobilise, and direct efforts of a range of actors such as industries, research institutes, educational organisations and financial institutes along strategic visions set out by government in interaction with research institutes and industries (Freeman, 1988). Lundvall stressed the importance of interactive learning, for example between users and producers (1988), and focused on elements such as trust (and the formal institutions behind it) and mechanisms of exchange of tacit knowledge (based on skills, experience, and routines) in innovation processes (1992, 2002). Nelson has also shifted from an evolutionary to a more co-evolutionaray approach and emphasised the importance of "*institutional structures in supporting and* *moulding efforts to advance technology*" (Nelson, 2002: 265). The understanding that institutional structures for the creation and application of knowledge differ across nations is fundamental to the NSI approach. This does not imply that they render sectoral patterns of interaction between firms, suppliers and users, and internationalisation of knowledge generation and industrial strategies irrelevant but that national styles of knowledge generation, transfer, and application tend to have a more profound impact on innovation patterns and their success. Moreover, the set-up and development of institutional frameworks that enable and constrain interactions between firms, interactions between firms and knowledge actors, and between science and government, are considered to be still dominated by national settings.

This is illustrated in research on the nature of the interaction between science and government and the way these bring forth particular research priorities, directions, and programmes. In a comparison of these interactions in the different national settings of the UK, Germany and the Netherlands, Van der Meulen (1998) points at path dependence in the relationship between science and government. The way interactions between science and government are institutionalised has a strong influence on outcomes, implying, for example, that the use and implementation of a new policy instrument (foresight in the work of Van der Meulen) to explore promising research directions may result in reproduction of ongoing strategy processes when it is not accompanied by higher order institutional adaptation (Van der Meulen, 1998: 411). The nature of the institutional arrangement "*structures the strategies of actors within the implementation of new policy instruments*" (ibid.: 412).

Others point out that the nature of the way knowledge is generated, distributed and applied is fundamentally changing in a process of co-evolution with societal change. Smits (2002: 862) argues that "*shifts in the context of innovation processes, more particularly the emergence of the 'porous' society, will lead to a radical transformation of innovation systems in which (knowledge intensive) intermediaries and the quality of the interface between users and producers play an increasingly important role*". Related to this Smits and Kuhlmann (2004) explore the rise of, and need for, 'systemic instruments' in innovation processes. They identify several functions that play an important role in current innovation processes: 1) management of interfaces; 2) providing platforms for learning and experimenting; 3) providing an infrastructure for strategic intelligence; 4) stimulating demand articulation, strategy and vision development. Existing policy instruments only fulfil part of the systemic functions, and further development of systemic instruments is called for. This especially includes strengthening of the intermediary infrastructure comprising of institutions, mechanisms and organisations aimed at improving the interface and exchange of knowledge between the supply side and demand side (Smits and Kuhlmann, 2004 : 16).

Path dependence

What all the previously analysed theoretical streams have in common is elements of so-called path dependence play a role in innovation processes. Evolutionary economists tend to stress the role of increasing returns to adoption through which apparently inferior designs can become locked-in through a path-dependent process in which timing, strategy and historic circumstances, as much as optimality, determine the winner (David, 1985; Arthur, 1988). The classic example is of the QWERTY keyboard, which was designed to prevent keys from cluttering, but remained dominant after this technological problem was solved. Due through accumulation of competencies (peoples' ability to type based on the QWERTY keyboards), accumulated investments, standards, various improvements of the keyboard faced rejection by the market (David, 1985). Arthur (1988) later developed economic principles that underly lock-in to particular technological designs. Increasing returns to adoption are seen to create positive feedback loops that strengthens the position of a technology relative to competitors. Examples are learning effects, with accumulation of experience as the technology becomes more adopted and used, thus leading to further development of skills and competences and enabling clearer paths for improvement; network externalities, with the availability, variety, and service regarding the particular technology increasing as more users adopt it; scale effects, with economies of scale reducing production costs for the technology; and technological interrelatedness, with more and more technological components becoming part of the infrastructure for the adopted technology (Arthur, 1988: 591). All these path-dependent features are of relevance for the electricity system and form part of the explanation for the difficulty of developing and expanding alternatives. Moreover, at the level of technological systems the emergence of a dominant design that incorporates both technical and social elements (for example monopolistic organisation in the case of the electricity sector) facilitates system expansion in its early phase but also can hamper renewal as suboptimal technologies may be chosen because of a better fit with the existing dominant design and superior technological variants do not necessarily win (Unruh, 2000). Especially the way certain institutional arrangements become intertwined with technological configurations is an issue we will touch upon repeatedly in the remainder of this book.

Systems change in long wave theory

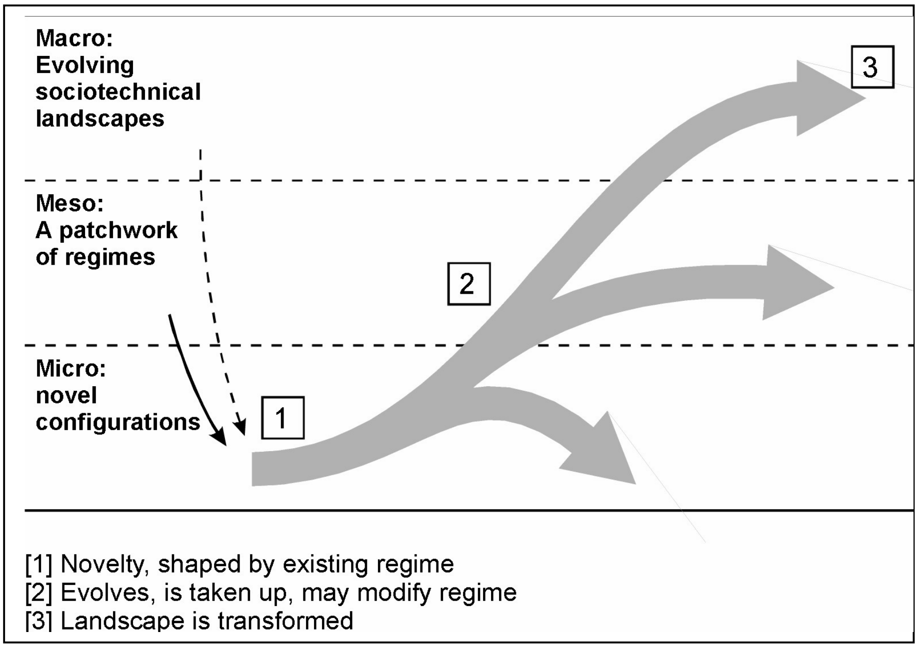
Freeman also focuses on systems change in a broader sense in his analysis of long waves in economic development (Freeman and Perez, 1988; Freeman and Louca, 2001). The development of specific clusters of technologies fuels growth in different economic eras and is accompanied by institutional structures that support and enable exploitation of these clusters (Perez, 1983). Freeman and Perez (1988) take path dependence to a new level beyond that of a technological system in their idea of a techno-economic paradigm as a "*cluster of interrelated technical, organisational and managerial innovations, whose advantages are to be found not only in a new range of products and systems, but most of all in the dynamics of the relative cost structure of all possible inputs to production. In each new paradigm a particular input or set of inputs may be described as the 'key factor' in that paradigm characterised by falling relative costs and universal availability. The contemporary change of paradigm may be seen as a shift from a technology based primarily on cheap inputs of of energy to one predominatly based on cheap inputs of information derived from advances in microelectronic and telecommunication technology*" (Freeman, 1988a: 10). What Perez (1983) especially stressed was that systems change can only take place through a combination of profound social, organisational and technical innovations. This is not a smooth process because there are "*strong vested interests associated with the previous dominant paradigm and the regulatory regime and cultural norms associated with (…*it)" (Freeman and Louca, 2001: 148). While the expiring era was based on institutionalised mass production and consumption, Fordist organisational forms, and hierarchical structures, the upcoming era is characterised by networks: internal, local and global (Freeman and Louca, 2001: 141). Thus, a new techno-economic paradigm is gaining ground, creating a new constellation that synchronises scientific, technological, economic, political and cultural developments. The ideas put forward here are very significant for our analysis of the electricity system, on the one hand because the shift to information technology and a network society is a factor in shaping the development of the electricity system, and on the other hand, because the focus on interaction between technical, organisational, and institutional innovation is the starting point for our analysis.

Sociotechnical change theory

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; Bijker and Law, 1992; 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. The concept of path dependence is useful in order to explain why, despite clear intensification of environmental pressures, policies have often not been able to foster fundamental changes in production and consumption. Environmental measures, technologies and policies initiate from the accumulated technologies and competencies that have brought forth technological systems entrenched in various institutional structures and embedded in society. Rip et al. (1995) point out how the institutional division between promotion and control of technology leads to development of technologies that produce unforeseen side-effects, whereas control and regulation of these side-effects only takes place once the technology has penetrated firms, markets and society. They argue for constructive technology assessment where more anticipatory processes are set in motion in order to reduce harmful effects of technology to emerge. The rationale is also that it is more difficult to change a technology once it has already entered the market place.

Here sociotechnical change theory also shares common ground with new institutional theory (March and Olsen, 1989; Powell and DiMaggio, 1991; Guy Peters, 1999) that points to the importance of institutions (both formal and informal rules) as sources for path dependence. 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 dominated by gradual improvement of dominant systems and are, consequently, unable to bring forth fundamental systems change. Sociotechnical change theory points to collaboration as a way out of this deadlock. Social networks are key both in the stabilisation of present technologies and, potentially, in the creation of new ones (Weaver et al., 2000). A focus on system optimisation occurs 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. From a similar perspective Schot (2001) proposes to broaden the design process of technologies by bringing together all interested parties early on and throughout the design process. In this way potential for mutual learning regarding technological options, user preferences, institutional aspects and environmental impacts can be fully exploited and facilitate embedding of new (sustainable) needs and values in material (technology) realities (Schot, 2001). In sum, sociotechnical change theorists aim to increase understanding of the dynamics and patterns of co-evolutionary processes that inform where opportunities exist to trigger new actor linkages and alignments which can enable the creation of new transformational paths (Kemp, Rip and Schot, 2001).

Figure 2.2 Multiple levels shaping dynamics of sociotechnical change (Rip and Kemp, 1998: 339)



A multi-level perspective on systems change

A group of researchers originating from the Netherlands has been influential in developing a specific analytical perspective on systems change or transitions as they label it (Rip and Kemp, 1998; Kemp et al., 1998, 2001; Geels, 2002a, 2004). They have been concerned with the way more radical innovations come about and penetrate into society. To understand transitions a multi-level perspective is developed that builds upon insights from the field of sociotechnical change. The core of the theory is that transitions are shaped by interaction between three levels: the socio-technical landscape, the socio-technical regimes and niches (see Figure 2.2). Sociotechnical systems are located at the meso-level and are characterised as regimes to indicate a set of shared rules that guide and constrain the work of actors within a production and consumption system. The notion as developed by Rip and Kemp (1998) is broader than the concept of technological paradigm of Dosi that centres on engineering principles, and comprises also the way technological systems are embedded in society. Engineering heuristics are aligned with rules of the selection environment (Rip et al., 2001: 272).

Regime-shifts – systems change – occur as follows according to this school of thought. A novelty emerges in a local practice and becomes part of a niche when a network of actors is formed that share certain expectations about the future success of the novelty, and are willing to fund further development. The niche is formed against the background of the existing regime and landscape. Niches may emerge and develop partly in response to pressure and serious problems in an existing regime which can be either internal to the regime itself (such as power failure) or come from the socio-technical landscape (e.g. the current pressure to curb CO_2 emissions which affects more than just the electricity regime). The further success of niche formation is on the one hand linked to processes within the niche (micro-level) and on the other hand to developments at the level of the existing regime (meso-level) and the sociotechnical landscape (macro-level). Supported by actors willing to invest in the concept (industries, R&D organisations, government) and protected from competition at the market place, the technology is improved within the niche, broader networks are formed around it, and more is learned about technical directions for improvement and functions it may fulfil. After some level of improvement of the technology, and after learning more about its potential, it may find its way in specific market applications, often typical segments that exploit new functional characteristics of the technology and focus less on cost structures (e.g. PV panels for satellites). Through further improvement, increasing reliability, and cumulated experiences and learning about functionalities and potential applications the technology can spread to other market niches and/or trigger expansion of the market niches. Processes of rule formation also play an important role, such as the development of standards for the technology, and processes to reduce the mismatch of the emerging technology with the rules of the dominant regime. As it starts to compete on or with main markets, the technology may transform or substitute the existing regime. In a later stage, the new regime may even trigger changes at the landscape level (e.g. the computer regime leading to applications such as the internet with its pervasive impact on society).

Sociotechnical systems such as the electricity and transport systems are in this perspective characterised by heterogeneous elements such as technology, infrastructure, knowledge, regulation, industrial organisation and user preferences that have become mutually attuned. Weak and strong linkages occur between the different elements, and are solidified by sets of rules which act as a semi-coherent structure for the development of both technological and social components in a system (Kemp, Rip and Schot, 2001). Actors and social groups within the system maintain, confirm and reproduce these rules through their activities and practices which are nested within the systems. Often these rules are taken for granted, such as the way a prospective house buyer expects his house to be connected to the grid and to be equipped with electricity sockets. They also involve formal rules, such as those prescribing under which conditions an actor can enter a professional activity (accountant, lawyer, doctor, electricity producer), or environmental and safety standards. The multi-level perspective especially points out how this rule-set can act as a barrier for new technologies, and that processes of niche formation thus not only involve improving technological and economic performance of new technologies, but also manoeuvring the new technology in a way that it can work in the existing sociotechnical configuration, through a process of negotiating and mobilising for changes in the dominant rule-sets, or through a process of building alternative rule-sets. Failure of alternative energy technologies can then occur through mismatches with existing regime-rules, as Raven and Verbong (2004) show in their analysis of manure digestion and heat pumps in relation to agricultural and electricity regimes. Geels (2002a) also showed how alternatives may succeed if existing regimes come under pressure, and if the new technology is able to provide additional or new functionalities in co-evolution with broader societal changes.

A short synopsis: innovations and systems change

After characterisation of the way a range of theoretical streams deal with and conceptualise innovation and systems change, this section provides a short overview of basic insights of a range of scholars regarding the ways and conditions under which systems change may occur.

Basanini and Dosi (2001) argue that windows of opportunity occur for systems change because:

- New technological paradigms emerge, acting as a major source of delocking (these can trigger emergence of a new set of business actors, a new knowledge base, new communities of practitioners (e.g. scientists, engineers), and new forms of corporate organisation).
- There is never a complete lock-in, as heterogeneity among actors and imperfect adaptation of actors within organisations and networks leads to variety. Thus, non-average actors can create effects of change.

- Misadaptation between organisational routines can increase and, (1) their problem solving efficacy, and/or (2) and their ability to represent mechanisms of organisational governance and social control.
- New organisational forms that originally develop in other contexts can invade into the system.

Cowan and Hulten (1996) argue that overcoming existing lock-in (to the internal combustion engine of the car in their case study) requires extraordinary events such as:
- a crisis in the technology involved;
- regulation;
- technological breakthrough;
- changes in taste;
- niche markets;
- scientific results.

Kash and Rycroft (2000: 826-828) argue that shifts in the patterns of the innovation of complex technologies occur through:
- technical community disintegration: this refers to the loss of consensus concerning what comes next, replacing the consensus (common knowledge, established search heuristics and routines) regarding the next series of incremental innovation;
- invaders: networks or organisations entering innovation processes and becoming new competitors based on different knowledge and capabilities that allow them to breach the boundaries of the established trajectory, or based on different organisational forms, such as lean production by Toyota.
- new technology waves: technologies become available with distinctly different and better performance across a wide range of sectors, such as digital electronics;
- external change: this refers to changes in markets (e.g. market saturation), changes in public policy, and changes of a social nature such as increasing pressure from societal groups with regard to environmental or consumer risks.

Unruh (2002) separately focuses on two potential sources for escaping carbon lock-in, (1) technological, and (2) social/institutional, but adds that the process of escape should not be seen as the result of a single change, but rather a series of complex, interconnected changes in multiple variables.

Berkhout et al. (2002: 15) link the nature of transitions that may unfold to the vulnerability of a regime to selection pressure. "*We may posit the existence of actors having either highly asymmetric or more balanced sets of competences and resources (the greater the imbalance, the less vulnerable is the regime). Likewise we could characterise networks as being either tight,* *cohesive and closed, or more open and differentiated (the tighter and more cohesive, the less vulnerable). Last, we may imagine institutional arrangements that impose high switching costs on incumbent regimes and that promote good connectivity within it, or alternatively a set of arrangements that tend to reduce switching costs (perhaps by giving incentives for switching) or promote better connectivity within competing regimes. Again the former arrangement would tend to favour an incumbent regime. In practice it is likely that different regimes will exhibit different sets of characteristics at different points in time, dynamically reshaping the profile of their robustness or vulnerability*". For a regime change to unfold, they argue that "*it must be recognised as necessary, feasible and advantageous by a broader range of actors and institutions than would normally be the case for a discrete technological change*".

If we sum up this overview we can discern between factors exogenous to the regime (external shocks and scientific results), either exogenous or endogenous (technological breakthroughs which can occur either from inside or outside the regime; new organisational forms, institutional changes), and endogenous (misadaptations, tensions within the regime, changes in preferences and niche markets (although probably exogenous factors play a role in explaining, e.g. environmental concerns, ICT penetration), and non-average actors. We basically adhere to the formulation of Unruh (2002) that for a process of transition such as escaping carbon lock-in several interconnected changes will have to take place, both initiated from within and outside the regimes, and consisting of combinations of institutional, organisational and technological changes. Although maybe this is not much of a help, it on the other hand makes clear that there may be a range of developments available to which new innovations may hook on to. Moreover those innovations that emerge at the intersection of different regimes may gain strength by exploiting combinations of tensions in different regimes. This bears some similarity with remarks made on cluster development by Porter (1998: 241) that "*cluster development often becomes particularly vibrant at the intersection of clusters. Here, insights, skills, and technologies from different fields merge, sparking new businesses. The presence of multiple intersecting clusters further lowers barriers to entry, because potential entrants and spin-offs come from several directions. Diversity of learning stimulates innovation*".

2.3.2 The nature of institutions, institutional change and its contribution to systems change

The importance attributed in this thesis to the role of institutions and institutional change in systems change demands a more careful consideration of these concepts and their roots. We provide a short introduction of the concept of institutions and institutionalisation and follow with an overview of several approaches that integrate institutional change within their theoretical concepts, institutional economics, the new institutionalism in organisational analysis, and ecological modernisation.

Scott (2001: 48) conceptualises institutions as follows:

– Institutions are social structures that have attained a high degree of resilience;
– Institutions are composed of cultured-cognitive, normative, and regulative element elements that, together with associated activities and resources, provide stability and meaning to social life;
– Institutions are transmitted by various types of carriers, including symbolic systems, relational systems, routines, and artifacts;
– Institutions operate at multiple levels of jurisdiction, from the world system to localised interpersonal relationships;
– Institutions by definition connote stability but are subject to change processes, both incremental and discontinuous.

The way institutions become established can be termed institutionalisation. Institutionalisation refers to increasing coordination of activities through institutions of a regulative, normative and cognitive nature (Zucker, 1988; Holm, 1995; Scott, 2001). As representatives of the cognitive approach Meyer and Rowan (1977: 341) define institutionalisation as involving "*the processes by which social processes, obligations, or actualities come to take on a rulelike status in social thought and action*". A further important concept is that of legitimacy, which expresses the continuous need to be able to justify and explain why things are done in a certain way (Berger and Luckmann, 1966: 58; Scott, 2001: 58-61). Opposite to institutionalisation one can speak of de-institutionalisation involving weakening or disappearance of institutions (Oliver, 1992; Scott, 2001).

New institutional economics

A predominant focus on institutions of a regulative nature is visible in the work of economists such as Williamson (1981) and North (1990). Williamson points at the transaction as the basic unit of economic analysis and sets out to clarify why certain transactions take place within firms and others within markets. His main premise is that transactions may be costly due to their specificity, the bounded rationality of actors, and the possibility of deceit by interacting parties (Williamson, 1981: 553-555). In order to make transactions as efficient as possible, governance structures need to be "*tailored to the specific needs of each type of transaction*" (Williamson, 1981: 568). Governance structures may vary from organisation of exchanges within firms, between firms, through contracts and contacts, and on markets. Williamson's thesis is that when transactions become more uncertain and asset specific, they are more likely to be produced in-house because choice of that institutional form leads to most efficient transaction costs. Williamson has been criticised for treatment of institutions as representing a mere choice of actors wishing to reduce transaction costs or the "*efficient solution to certain economic problems*" (Granovetter, 1985: 488), instead of taking into account the way transactions take place in a web of social relations (Granovetter, 1985). Outside the firms this may imply that personal relationships, friendships, and trust that is built up lowers transaction costs (drawing on the normative pillar of institutions), while inside the firm a web of informal relationships may reduce the expected efficiency of hierarchical decision making (Granovetter, 1985: 502). Following this, Granovetter's thesis opposite to Williamson is that pressures towards vertical integration should be absent in a market where "*a stable network of relations mediates complex transactions and generates standards of behavior between firms*" (Granovetter, 1985: 503). Williamson's static transaction cost theory is recently also modified towards a dynamic theory of transactions that incorporates a more cognitive approach to actor behaviour, focuses on innovation and learning, and brings in trust next to deceit (Nooteboom, 1999). Particularly relevant is his focus on cognitive scope and his argument that people and firms need outside source of cognition and competence to complement their own, especially for innovations. Thus, for firms, inter-firm linkages may produce more innovative behavior than relationships between vertically or horizontally integrated business units. Interactions between units with shared standards, norms, and (business) culture produces less novel ideas and practices than interaction between firms with differences in experiences, standards, norms and business culture. Although Nooteboom does not mention it explicitly, he touches here upon some of the key ideas in social network theory, about the way social structure may affect economic outcomes, such as innovative processes (Granovetter, 1985; 2005).

A much broader notion of institutions that affect transaction costs and economic performance is adopted by North (1990). According to North (1990: 3) "*institutions are the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction*". In his definition of institutions, formal constraints through regulations and informal constraints through culturally established norms are the basic elements. An important point North raises is that history matters, implying that institutions evolve along a certain path that is not easily re-directed or fundamentally modified. North argues that institutions show path-dependent features in a similar way as is shown for technologies (David, 1985; Arthur, 1988).

New institutionalism in organisational theory

New institutionalism in organisational theory approach institutions as socially constructed, routine-reproduced program or rule systems. Contrary to the regulative and normative approaches in institutional economics here the focus is particularly on the way shared cognitions and taken-for-grantedness of certain ways of doing things as exemplified in the "*homogeneity of practices and arrangements found in the labor market, in schools, states, and corporations*" (DiMaggio and Powell, 1991: 9). An example is the work of Tolbert and Zucker (1994) who aim to understand the way certain organisational structures diffuse across industries. They conceptualise a sequential process of institutionalisation where innovative organisational forms become fully integrated and taken for granted as they move through three phases. In the first pre-institutionalisation phase of habitualisation the new structural arrangements are born in response to specific organisational problems and become formalised in policies of procedures in some organisations facing the same problems. As adoption of the new practice is still low, not many organisations will be aware of it, and knowledge exchange regarding the new practice, on its purpose and effects and the way it may be implemented, is very limited. In the second semi-institutionalisation phase some degree of consensus is developed by decision makers in organisations as to the value of the new practice, and increasing adoption takes place on the basis of this consensus. They call this process objectification in the sense that increasing generalisation takes place regarding the value of the new practice, also because pre-testing has occurred in early adopters. In this phase diffusion may be facilitated by so-called 'champions', a set of individuals with a material stake in the promotion of the structure (DiMaggio 1988). The final process towards full institutionalisation is termed sedimentation by Tolbert and Zucker. This involves survival of the new practice over a lengthy period of time and across generations of organisations. "*Full institutionalization of a structure is likely to depend on the conjoint effects of relatively low resistance by opposing groups, continued cultural support and promotion by advocacy groups, and strong positive correlation with desired outcomes*" (Tobert and Zucker, 1994: 24).

In their analysis of the emergence of the early automobile and biotechnology industries Rao and Singh (2001) argue that institutional factors are crucial in explaining emergence and decline of industries. Through a process of building legitimacy new forms "*have to be justified and integrated into the prevalent institutional order*" (p. 264). In both cases it was a political process "*because support has to be mobilized for the goals, authority structure, technologies and clients embodied in the new form. In the case of the early automobile industry, opposition from vigilante antispeed* *organizations jeopardized the standing of the automobile, and had not automobile clubs played an active role in defusing opposition, the industry might have faced stringent legal constraints on the use of cars. Similarly, in the biotechnology industry, concerns about the dangers of rDNA technology and threats of reckless organisms might have led to restrictive laws had not professionals quickly devised voluntary safeguards, and forestalled governmental intervention*" (Rao and Singh, 2001: 263). The importance of creating and maintaining legitimacy is also confirmed by authors such as Oliver (1992) and Suchman (1995). Oliver (1992) shows how reduction in legitimacy, such as when changing societal values become shared and represented by governments, or when higher efficiency standards are set by government bodies, may lead to de-institutionalisation.

The approach utilised by Holm (1995) in understanding institutional dynamics of changes in Norwegian fisheries is useful. Holm (1995: 400) uses a nested systems perspective: "*A distinction is made between action guided by institutions, on the one hand, and action aimed explicitly at manipulating institutional parameters, on the other*". We feel this distinction is valuable, because it represents two different playing fields, comparable to playing chess at the chessboard on the one hand, and on the other hand trying to change the rules for chess within a rule-making body such as the FIDE[5]. Apart from discerning between practices guided by institutions and practices intended to manipulate institutions, it is also possible to distinguish institutions that represent ground rules (or fundamental rules) and specification rules that specify, and built upon, ground rules, such as proposed in a similar form by Coriat and Weinstein (2002).

Ecological modernisation

In ecological modernisation theory several scholars have aimed to explain how increasing attention for environmental problems has been translated into institutional change processes within specific industries. Ecological modernisation theory is concerned with how contemporary industrialised societies deal with environmental crises (Mol and Sonnenfeld, 2000). It proposes that environmental reform of the modern organisation of production and consumption can shape a path towards sustainable development based on the idea that collaboration of key actors such as government, industry, reform-oriented environmentalists, and science, can generate win-win outcomes of economic development and environmental improvement. This takes place through a process of institutionalisation of ecology in the social practices and institutions of production and consumption, implying new 'rules of the game' for the social organisation of

5 International Chess Federation.

production and consumption (Mol, 1995: 29; Van Vliet 2002: 14). Mol (1995) analyses environment-induced institutional transformations in the Dutch chemical industry. He evaluates six hypotheses central to ecological modernisation theory to investigate the explanatory potential of the theory. Basically they contend that ecological considerations become increasingly integrated into the economic, political and societal sphere. Thus in modern society the ecological sphere gains growing independence, emancipation and empowerment (Mol, 1995: 63). The analytical model Mol uses is the so-called triad-network approach. According to Mol this approach is useful for analysing meso-level transformations (economic sectors) which is the level most appropriate to understand changes in production-consumption systems[6]. Moreover the networks in the approach can be directly related to the basic tenets of ecological modernisation theory as the networks represent the economic, political and societal sphere. He distinguishes three interdependent networks, the policy network, economic network, and societal network. Each network has its own restricted number of interacting actors (labelled core and peripheral actors) and its own distinctive institutional arrangements.

For the policy network Mol focuses on four dimensions: 1) the rules of the game; 2) the different resources used; 3) the strategies between industry and government, and 4) the appreciative systems. Rules of the game concern the way interactions take place (e.g. from few contacts, diverging interests and a confrontational nature to regular consultation, mutual trust and respecting each others interests and confidences with less use of legal remedies in the case of one industrial branch); and the level of openness of the network (both in terms of actors and of issues). With regard to resources Mol pays attention to the distribution and use of legal resources (authority), economic and financial resources, and informational resources. Strategies can include insulation (keeping government away), penetration (e.g. by industry in government to safeguard interest), mutual adaptation, and interorganisational concertation (co-operation through mutual understanding of each other’s position and interests). Appreciative systems concern the dominant ideology or world view in the policy network that promote and legitimise specific action strategies (or solutions) (Mol, 1995: 71).

For the economic networks Mol analysed, inspired by the industrial network approach, in what way and to what extent interactions (vertical, horizontal and other) between constituents of industrial networks remained the same or transformed in confrontation with the stronger emergence of environmental

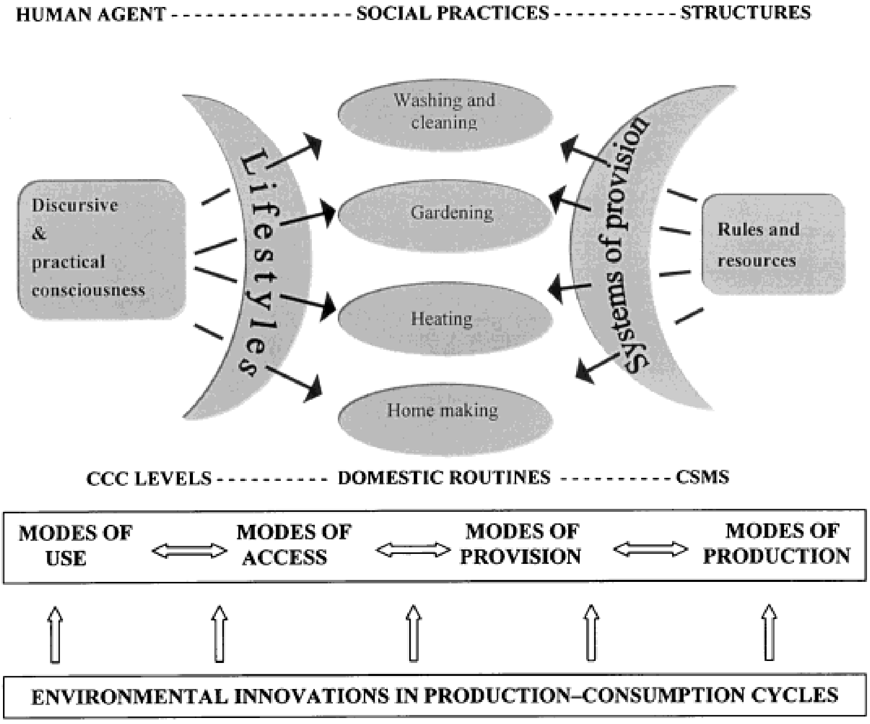
6 According to Mol (1995: 62) analysis at the micro level may miss inter-firm changes and sectoral changes, while the macro-level would abstract from relevant environment-induced inter-firm transformations by putting too much emphasis on the net national effect.

issues in industrial societies (Mol, 1995: 77). His focus is on the distribution of and shifts in power and resources, and on formal and informal rules as structuring principles. Formal rules are economic rules on for example profits, ownership, patents, liability, planning, investment decisions. Equally relevant are informal rules on trust, negotiations, cooperation, etc. Rules can change due to environmental considerations as for example environmental quality of products becomes part of the demand structure, by extending liability with environmental liability, by taking environmental management standards into account when judging good entrepreneurship (Mol, 1995: 78).

The societal networks depict the relations between industry and civil society. Examples of organisations in the societal network are labour organisations, consumer organisations, environmental organisation and local citizens groups. The focus is on how interactions are shaped (direct/indirect interaction) and changing. Further focus is on rules and resources applied in societal networks that primarily centre around legitimisation and signification of industries' production and products. Ecological modernisation theory hypothesises strategies and ideologies of environmental organisation developing towards more direct interactions with industry and support for environmental progressive entrepreneurs, while challenging the laggards. Industry will increase negotiations and private agreements with environmental NGOs on environmental reform (Mol, 1995: 83).

Van Vliet (2002) analyses environment-induced change in network bound systems of provision and consumption, with case studies of electricity and water provision. His focus is on social practices and the role of citizens-consumers in order to gain insight in the relationship between action and structure, inspired by Giddens' (1984) structuration theory. Important is the concept of duality of structure in which on the one hand actors are constrained in their actions to draw on existing rules and resources and structures are thus media enabling human actions, and on the other these structures are confirmed and reinforced by human action, and are thus also outcome of it (Van Vliet, 2002: 12). These ideas have been conceptualised earlier by Spaargaren as shown in Figure 2.3.

Figure 2.3 Model of analysis for consumption practices (Spaargaren, 2000: 327).



In his thesis he explores social practices of consumers both from the analysis of strategic conduct as well as through institutional analysis. This is relevant as the role of citizen-consumers is, according to Van Vliet, underrated in the study of technological change. Based on assumptions derived from ecological modernization theory he analyses several case studies of monitoring and differentiation as an expression of environment induced change in network bound systems and particularly the way consumption is connected to modes of provision. The duality of structure is especially visible through the focus on system of provision. Consumption practices are partly shaped (or constrained) by systems of provision enabling them. User's routines are shaped by the technological system but this does not imply that user preferences are fixed, only that it is very difficult to change them as they are interwoven within the system. Thus the central station electricity system[7] with monopolistic organisation has shaped captive, passive consumers. Van Vliet stresses the significance of electricity as relying on an expert system, where a shift to another system cannot take place because of

7 Electricity generation in a number of central, often large-scale, production facilities and transmission and distribution through an extensive infrastructure to users.

sunk costs and the perceived impossibility and inefficiency of such a shift by the dominant actors (2002: 20). Using water and energy is a daily routine, which may be changed only through interruption of routines (power fall out or removal or home reconstruction project) or when discursive awareness awakens (aware of the skills necessary to uphold the system, linkages, power relationships). This discursive awareness can also be directed to the environmental impacts that characterise the present make-up of the system. The success of green electricity in the Netherlands, for example, suggests however that groups of consumers can change their routines to some extent if the mode of provision enables this and they acquire sufficient motivation and information. According to Van Vliet making visible both environmental impacts and the structures that uphold them provides a mechanism to open up the system for change. Van Vliet argues that "*environmental monitoring can increase the visibility of systems of provision to its users, and thereby lower the threshold for environmental renewal*" (2002: 131). Also important here is the symbolic dimension of consumption as an expression of culture: people use goods and services to relate to other people or groups. He further concludes that "*environmental differentiation is a second core issue because it inherently marks a transition from uniform provision in network-bound systems towards dispersed, pluralist modes of provision. Such a transition is a prerequisite for the development of those environmental innovations that do not fit in the technological trajectories that characterise the phase of uniform provision*" (2002: 131).

The approach used by these ecological modernisation scholars is useful as it includes institutional contexts and processes into the explanation of environment oriented innovation and develops a research approach where the focus is on co-evolution between technical and institutional innovations emerging and reproduced in the networks which are studied. This type of network analysis is useful to understand patterns of change, although there is no specific attention for type of reform that can facilitate more radical changes. The approach is useful in analysing changes, but convinces less in explaining why these changes come about and why in these specific configurations. Moreover, there is some lack of specificity regarding the mechanisms through which environmental pressures lead to changes at the level of firms and their networks.

Governance theory

Governance theory has in the last decade analysed new forms of steering alternatives to hierarchical control models, especially more on co-operation focussed models in which governmental, non-governmental and private actors participate in mixed public and private networks (Mayntz, 1998). For example, environmental governance models emerge as alternatives to traditional forms of direct regulation because it becomes evident that conventional command-and-control models are not able to cope with 'wicked' environmental problems (Bressers, 1991; Bressers and Kuks, 2001, 2003). Governance points to the interdependence among actors, their interactions, and the rules associated with them. It also points to the importance of collaboration as "*no single actor, public or private, has all knowledge and information required to solve complex, dynamic and diversified problems*" (Kooiman, 1993:4). Governance theory recognises the increasing importance of civil society, for example, in co-setting the agenda in processes of local and global environmental change.

Governance thus diverges from paradigms where either hierarchy or the market is the dominant organisational form, and emphasises the role of networks in organising relations between actors. Dominant processes of governing in networks concern negotiation, accommodation, concertation, co-operation and alliance formation, rather than the traditional processes of coercion and command and control. In environmental policy, the increasing interest in the concept of governance has shaped the emergence of co-operative environmental strategies between public and private actors. Examples are voluntary agreements between industry and government (Glasbergen, 1998) and the stimulation of environmental management in firms through the use of policy networks based on consensual steering models (De Bruijn and Lulofs, 2000). The involvement of partners such as national governments, business, and consumers is also seen as crucial in European environmental policy. The fifth Environmental Action Plan of the European Union for instance stresses the importance of shared responsibilities among governments, business and the general public out of the understanding that the ultimate goal of sustainable development can only be achieved by relevant actors working together in partnership (CEC, 1993: 113). Understanding the relation of the nature of governance to patterns of system innovation has more recently emerged as a research topic (Rotmans et al., 2000, 2001; Grin et al., 2003, 2004; Grin, 2004; Rotmans, 2005). Rotmans et al. (2000) argue that transitions commonly take place in four phases: predevelopment (with little visible change but ample experimentation), take-off (the system begins to shift as change gets under way), acceleration (structural change takes place through accumulation of socio-cultural, institutional and economic changes reacting to each other), and stabilisation. According to them the nature of government intervention should be tuned according to the phase in which the transition is. Rotmans et al. (2000, 2001) developed the notion of transition management which tries to orient existing dynamics towards transition goals chosen by society. The underlying idea is that through a focus on long term goals of sustainability and its attention to dynamics the conflict between long-term ambition and short-term concerns can be overcome. Key elements are the formulation of a transition goal and the use of process management based on a philosophy of learning-by-doing and doing-by-learning and the evaluation of actual policies and goals development rounds (Rotmans et al., 2001). Grin et al. (2004) point more at the need to bring to scrutinise taken-for-granted assumptions and roles of actors in order to develop alternative problem perceptions and solutions. In line with earlier work from Grin and Van de Graaf (1996) and Hoppe and Peterse (1998) they propose an approach of deliberative policy analysis where the focus is "*to define both a problem and solution in a process of reciprocal, argumentative exchange between the actors involved in the problematic*" (Grin et al., 2004: 127-128). Actors with established frames of references regarding existing practices, their problems and solutions, are confronted with alternative ways of interpreting these practices, and with different problem definitions and corresponding solutions. Through the development of shared problem definitions and solutions the idea is that for each actor group involved a course of action is set out that makes sense for the specific actor group and contributes to solving the newly defined problem.

Whereas the concept of governance has mostly been associated with developments in the public sector, it also has impacted the corporate sector. The concept of corporate governance captures the increasing role of a variety of stakeholders, and deals with the way companies manage stakeholder relations. It also acknowledges that demands for better environmental performance, accountability and transparency increasingly emerge from civil society rather than the state, especially because companies' activities are more and more global in nature and difficult to capture in specific national boundaries (Bendell, 2000). Companies need a social licence to operate as well as the traditional regulatory licence (Warhurst, 2001), and research on governance focuses on corporate approaches in balancing social and environmental responsibility with profitability in interaction with its stakeholders (Halal, 2001).

The concept of governance refers to the interaction among actors in state, civil society, and industry, their interrelatedness at local, national and global levels, and has given rise to various co-operative strategies for environmental management and sustainable development. The strengthening of civil society through stakeholder partnerships has been a driving force for curtailing industrial pollution, conserving nature, and introducing more sustainable corporate practices (Shrivastava, 1995; Guha and Martinez-Alier 1997; Hofman, 1998; Lemos, 1998; Stafford et al., 2000). Academic research in this field has sharply increased in the last decade, but there is still need for theory building as to how and under what conditions these strategies contribute to sustainable development.

2.4 Integrating insights from various scholars

Drawing on the ideas of sociotechnical change theory innovation is conceptualised in this thesis as a process of co-evolution of technological and societal change, or in other words technology is socially shaped. Innovation is an interactive process and not a straightforward linear process where new ideas, principles or knowledge that emerge from the fundamental research community bring about innovations in the applied research community which are tested before its introduction and potential further diffusion into the market. It "*is not a process where actors (academia, laboratories, firms, users) intervene sequentially, but one during which durable links are created between these various players*" (De Laat, 1996: 34). Drawing from evolutionary economics, instead of focussing almost solely on artefacts, and the technical and economic problems and solutions related to them in the innovation process, the focus here is strongly on actors and the way their behaviour, perceptions, beliefs, and expectations are originating from previous experiences, accumulated knowledge and competencies, and from the routines they have developed.

This implies that present and future choices are conditioned by choices made in the past, which produces a dominant pattern of innovation of relatively predictable, incremental improvements by established networks and technologies that co-evolve along established trajectories (Kash and Rycroft, 2000: 822). This 'normal' pattern of innovation does not challenge the way technology is embedded in society and the 'rule set' implicit in the way it is configured. A fundamental starting point is thus that technology does not function independently, but that, in order to work, technology is part of a larger configuration that consists of mutually attuned elements such as infrastructure, knowledge, skills, industrial organisation, regulatory standards and cultural norms, through which the technology can be handled productively. Thus, in a large technical system such as the electricity system, organisations such as electrical equipment producers, utilities, and investment banks are aligned to components such as scientific books and articles, and education and research at universities, and to regulatory standards (Hughes, 1987: 51). The functioning of technologies involves linkages between heterogeneous elements (Geels, 2002a). The activities and interaction processes of actors are embedded in ensembles of social and technical components that make up a technological system, and are guided and constrained by rules and principles underlying the system. Rip and Kemp (1998: 340) use the term technological regime for this set of rules and define it as "*the rule set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of* *defining problems – all of them embedded in institutions and infrastructures*".

As a regime emerges and evolves, the different elements become strongly interwoven such as that the mental frames of actors will view the existing technological system as the natural way things work. As they fall outside their frame of reference alternatives will be intuitively rejected because the focus tends to be on problems and limitations associated with them as they are assessed on their fit with the existing technological regime. And clearly in the early stages of the development of a new technology a lot of imperfections can be pointed out. Therefore, there is a need for the inclusion of alternative frames of references into evaluation mechanisms to appreciate technological options that deviate from the incremental path, such as for example a focus on achievements and potential of new technologies. For this, however, cognitive barriers need to be broken down, such as those established by the fact that members of technological communities have undergone "*a long process of learning and socialization that produces deeply held assumptions about technology*" (Lampel, 2001: 307). They are often strongly rooted into existing regimes, cognitively, professionally, or even economically, and tend to develop evaluation routines that filter out information not consistent with their beliefs about technology. "*Data inconsistent with an individual's evaluation routines are either ignored or appear as noise. Data consistent with evaluation routines are perceived as information and cognitively rearranged in a manner that reinforces an individual's beliefs. Given bounds to rationality, this bracketing of perception occurs because individuals may be more interested in confirming their beliefs than in actively trying to disprove them*" (Garud and Rappa, 1994: 347).

This is but one example on the cognitive dimension of a regime that illustrates the difficulty of deviating from the technological path rooted in the regime. If we look at entrepreneurs, these continuously influence paths by setting processes in motion by putting new products on the market and by employing new technologies. This, however, predominantly involves innovative activities that incrementally built upon the regime in terms of artefacts, knowledge, infrastructure and technologies. Incumbent firms tend to develop incremental innovations based on their established organisational and technical capabilities, and on present ways of evaluation, within their existing networks and markets. The main point of these examples is that innovation is "*not a negation of the past, but an elaboration and extension in specific directions depending on the particular sequence of unfolding events*" (Garud and Karnoe, 2001: 1). This concept of path dependence is useful to explain how at different levels lock-in to certain trajectories of change, organisational structures, or modes of governance occurs.

2.4.1 Innovation as a path-dependent phenomenon

In order to be able to understand how path dependence can be escaped or in other words how processes of path creation occur, first the concept of path dependence is tentatively unpacked at different levels and for the key elements of regimes, as is illustrated in Table 2.2.

Table 2.2 Path dependent processes and outcomes at different levels

	Path dependent processes	Outcomes
Firm	Routinised behaviour, organisational routines, investment procedures, training, search heuristics based on cumulative knowledge, accumulated experience and competencies	Incremental innovation based on accumulated competences and established perceptions of return and risk and user preferences (markets), e.g. through cost-benefit analysis and calculated returns on investments; organisational forms shaped by technological factors (e.g. established design)
Network	Co-evolution of technology and networks along routines and heuristics based on core capabilities and established designs; network composition based on mainstream competences within existing technological fields	Shared beliefs and expectations; guiding principles for improvement within established design; optimisation of components and technologies within the existing system; single loop learning
Sector	Industrial organisation coevolves with the established design; tuning of production, distribution, consumption, infrastructure; formation of industrial standards (network externalities, technological interrelatedness); formation of environmental standards	Continuous system optimisation; industrial standards based on established design; standards based on what is state of the art 'within' the sector, 'capture' of regulatory system
Society	System configuration becomes embedded in society (mode of governance matches the system), system becomes intertwined with daily life ('electrification')	Societal demands are absorbed without fundamentally changing the sociotechnical configuration

At the level of the firm decision making processes are largely determined by the routines that have developed based on cumulative knowledge, accumulated experience and competencies. Based on this also search heuristics have developed to determine which direction of innovative activity may be worthwhile and which one not. What is worthwhile is defined from a firm's core capabilities[8] (Leonard-Barton, 1992) and from the established designs of technologies and products (Tushman and Anderson, 1986). The results are patterns of incremental innovation that introduce relatively minor changes to existing products, exploit the potential of the established design, and often reinforce the dominance of established firms (Henderson and Clark, 1990: 9). Based on Abernathy and Clark (1985: 5), Table 2.3 provides the type of innovation patterns that typically grow out of the existing system and its structures.

Table 2.3 Innovation patterns growing out of the existing system

Innovation aspect	Innovation patterns
1) Technology/Production	
design/embodiment of technology	improves/perfects established design
production system/organisation	strengthens existing structure
skills (labor, managerial, technical)	extends viability of existing skills
material/supplier relations	reinforces application of current materials, suppliers
capital equipment	extends existing capital
knowledge and experience base	builds on reinforced application of existing knowledge
2) Market/Customer	
relationship with customer base	strengthens ties with established customers
customer applications	improves service in established application
channels of distribution and service	builds on and enhances the effectiveness of established distribution network/service organisation
customer knowledge	uses and extends customer knowledge and experience in established product
modes of customer communication	reinforces existing modes/methods of communication

At the level of networks, firms are embedded in networks that co-evolve with the nesting of their products and technologies in product chains and technological systems. With regard to their innovative activities, the

8 Leonard-Barton (1992: 113) defines a core capability as the knowledge set that distinguishes and provides a competitive advantage. This knowledge set has four dimensions: skills and knowledge base, technical systems, managerial systems, and values and norms. "*All four dimensions … reflect accumulated behaviours and beliefs based on early corporate successes*" (p. 114).

composition of the network and the direction of their activities will reflect the existing knowledge base and the established technology design and will foster consensus about the problems that need to be tackled and the way they should be solved. In the words of Bijker and Law (1992:10): "*technologies are stabilized because the network of social relations in which they are involved – together with the various strategies that drive and give shape to the network – reach some kind of accommodation*". In the normal pattern of incremental innovation, network learning involves searching for knowledge close to previous learning activities and is mostly internal to the network, defined as local learning by Kash and Rycroft (2000: 823). "*With each incremental advance, local learning tends to become more focused and more dependent upon what has done before…Time pressures reinforce the path dependence of local learning…Often these time pressures lead to local learning that reject large quantities of knowledge. In our case studies success in incremental innovation was directly related to the capacity to only use the knowledge needed to solve the immediate problem*" (Rycroft and Kash, 2002: 26-27). In their analysis of six cases of complex technologies[9] Kash and Rycroft (2000, 2002) find that while patterns of incremental innovations take place in stable network along an established design, innovations of a more radical kind (either transitional other transformational in their terminology) require major modification or renewal of networks.

At the sector level, increasing adoption of particular technologies or products feeds processes of standardisation to facilitate compatibility between various components (technological interrelatedness), and to facilitate the large group of users accustomed to the product (network externalities). Co-evolution of industrial organisation and established design reflects the way linkages between production, distribution, use and infrastructure are organised along the dominant design of the technological system (e.g. large central electricity producers focussing on supply factors in the era of monopolistic organisation with captive consumers and very limited customer communication and marketing). The formation of standards based on what is state of the art 'within' the sector can generate 'capture' of regulatory system and lead to barriers to innovation.

At the level of society, technologies/products become embedded in every day life in the sense that routines of other actors become aligned to that of the established design. Thus, when people buy a house it is routinely expected that electricity wires and sockets run through the house and are appropriately connected to the grid. The question how electricity generation is taken care for and the possible choice for alternatives (such as generation

[9] I.e. turbine blades, cardio-imaging technology, audio compact discs, radiation therapy technology, micro-floppy disks, and microprocessors.

at the level of a house or neighbourhood through a possible set of generating options) does not occur. However, asking the question how the provision of warm water is fulfilled (which type, whose ownership) is a much more natural question as here the established design is one of providing heating equipment towards individual households (e.g. we see different types of co-evolution of form and function of technologies). In both cases a network of social relations has evolved that constrains and shapes action sets, decision algorithms and actor preferences (Bassanini and Dosi, 2001: 61).

2.4.2 Systems change: deviating from established paths and regimes

From the previous we can conclude that deviating from established paths is not an easy task. Just as people go through processes of socialisation, radical products and technologies also have to go through processes of socialisation in order to shape markets, to align with policies, and to become part of the knowledge infrastructure. Deviation can be successful if the innovation is successful in building a new constituency for the product or technology, through aligning actors and artefacts in an agenda for the further spread of the innovation, and by continuously reducing uncertainty regarding the direction of the innovation process. In a way then, it concerns setting in motion the same type of processes that have created the existing regime. Table 2.4 provides an overview of some of the changes that are necessary at the level of the firm, with a focus on characteristics of technology and production, and on relations with consumers. The table is derived from Abernathy and Clark (1985: 5) with a third column added by the author to indicate the sort of action necessary for a company to enable these type of innovations. These are changes that can be perceived as to be within reach of the innovator, in the sense that the company can probably influence them to a certain extent. We will follow this up with an overview of some of the changes that are less within reach of the innovator, and sometimes beyond its reach, such as those within policy and societal networks, and institutional changes.

What becomes clear from this general overview is that the type of changes implied in a radical innovation can be rather comprehensive and may involve the development of whole new networks for a company. It will involve changes in routines within the innovating company but may also imply changes in routines of customers and of other companies within the product chain, e.g. maintenance and repair firms that have to learn how to deal with the specific problems of this new product or technology. These changes often need to be accompanied with processes of institutional change necessary to support the introduction of the product/technology, to facilitate its diffusion, to create some momentum, and to secure that in its further diffusion the product exploits its sustainability potential.

Table 2.4 Radical innovation patterns and type of changes required

Innovation aspect	*Radical innovation patterns*	*Type of changes required*
Technology/ Production		
design/embodiment of technology	offers new design, radical departure from past embodiment	find out what kind of design fits both technology and society
production system/organisation	demands new system, procedures, organisation	gain experience with production techniques and organisation
skills (labour, managerial, technical)	destroys value of existing expertise	re-train workforce, recruit new labour, built new expertise
material/supplier relations	extensive material substitution; opening new relations with new vendors	search for reliable and cheap materials, find reliable suppliers
capital equipment	extensive replacement of existing capital with new types of equipment	find, develop appropriate equipment and reliable equipment suppliers
knowledge and experience base	establishes link to whole new scientific discipline, destroys value of existing knowledge base	tap and find new sources for type of knowledge required, built new knowledge base
Market/Customer		
relationship with customer base	attracts extensive new customer group, creates new market	find out what the new market is for the innovation, what are appropriate niche markets
customer applications	creates new set of applications, new set of customer needs	customise product/technology to potential application and user preferences
channels of distribution and service	requires new channels of distribution, new service, aftermarket support	modify and built up channels of distribution, service; develop competencies for maintenance
customer knowledge	intensive new knowledge demand of customer, destroys value of customer experience	set up pilots, test to analyse user behaviour to product/technology, develop means for educating users
modes of customer communication	totally new modes of communication required	develop appropriate modes of communication

The type of necessary institutional changes depends also largely on the nature of the innovation itself. In the famous case of the Post-it Notes, for example, the essential part of the innovation process was mainly internal to the company 3M. The inventor had to overcome strong barriers within the company related to existing evaluation routines, as this glue that didn't glue did not fit the frames of reference and routines within the company which were built up through years of experience in serving the office supplies the customers wanted. Basically, virtually all people in the company were unable to disengage from their existing products and markets and their existing mindsets, and were thus to appreciate the potential of this new product. To imagine a piece of paper that would eliminate the need for tape was almost unthinkable. Only because the inventor was convinced of its potential and committed to make it work, had a powerful personality ('champion'), and was able to mobilise others to share his vision regarding the invention, it was further developed (the idea to stick the glue on a piece of paper came from someone else within 3M), tested and marketed (by providing samples in and later outside the company, people in 3M became more and more convinced that this was a good business opportunity). From the invention of the weak glue to mass production of the product took a period of 12 years. As customers understood the usefulness of this product, and took it for granted in their office routines, Post-it Notes speedily became a natural part of the office supplies used. "*Path creation, in the case of Post-it Notes, involved the disembedding of an individual from localized structures of relevance and provinces of meaning, overcoming the inertia and momentum that he encountered, mobilizing others to work on an idea that was transformed over time, all the while being flexibly resolute with a vision of what might be possible*" (Garud and Karnoe, 2001: 20).

New ideas, concepts and technologies part of processes of systems change are of a different nature and demand more far-reaching changes than the case of Post-it Notes. They often imply fundamental change away from existing modes of production and consumption (e.g. small-scale photovoltaic power or distributed generation as means to generate electricity), changing and replacing infrastructures (e.g. a hydrogen-based society), and changing knowledge bases (e.g. fuel cell technology for cars and power generation vs. combustion engines and turbine technology). We suggest that some of the main barriers for these new products and technology are based on 'institutional fabric' that is missing and therefore there is a lack of alignment and linkages between different actors for the further development and diffusion of the product or technology. Institutional fabric is missing for the (re-)configuration of relations between producers and consumers; for dealing with and solving safety concerns, e.g. an absence of generally accepted safety standards for hydrogen delivery and storage; as regulatory frameworks have to develop such as regulations for CO_2 as a coolant and rules for integration of photovoltaic modules into rooftops; etc. Regarding the knowledge base institutional change is necessary to gain more public and private support for R&D on the new technologies, their components and materials, and the problems faced in establishing trajectories of improvement. This may imply a change of mindset for the bulk of technological community members who involved in technology programs towards acceptance of the potential of new product/technology or changes in the composition of selection boards altogether. It may also imply different roles of actors or key involvement of different types of actors in projects, related to the nature (or projected future design) of the technologies, such as a stronger role for municipalities to support local-based small scale energy technologies that replace or complement the existing central oriented system for electricity supply. In Table 2.5 we give an indication of the types of institutional change that may be necessary to facilitate radical innovations and further evolution into transitions.

Table 2.5 Possible institutional changes to facilitate radical innovations, and transitions

	Knowledge network	Market network	Policy/regulatory network	Societal network
Micro (actor-technology level)	Produce knowledge regarding new technologies; new foci in education and research	Establishing new routines for old or new actors	Establishing rules and standards for new technologies, building new capacities for policy actors	Changing user behaviour, e.g. communal electricity generation
Meso (industry, technological field, network-level)	Create new knowledge flows and networks, develop appropriate intermediary infrastructure	Establishment of new supplier-producer-user relations	Changing networks involved in policy formulation and implementation, adapting policy, styles, roles to emerging technological design	Changing roles and networks for societal actors, interfaces for facilitating legitimacy and acceptance
Macro (national, system level)	Adaptation of national system of innovation to design, knowledge requirements of new regime	Changing industrial relations, emergence of new industry, services, new types of organisation	Changing modes of governance, changing links between administrative levels	New ways of perceiving, using and producing electricity, changing lifestyles

In the next sections we will focus on theories that can provide complementary insights on the role of core elements in systems change: actors, networks and institutions.

2.4.3 Theorising about the role of actors in systems change

The role of beliefs, expectations and vision

Beliefs can be seen as culminations of knowledge, competencies and routines of actors embedded in specific ways of thinking. They are important because they tend to be intuitive, are often difficult to change, but can play a central role in decision making on innovations. It is essential to bring to the fore beliefs of actors, and to break them down in terms of the assumptions that underlie them. In the electricity system, for example, dominant actors (firms, experts) long believed that: 1) central and large-scale generation of electricity was technically superior, more efficient and more reliable, than small-scale decentral generation; and 2) the nature of renewable technologies made them unfit for this system because due to their discontinuous character it was impossible to integrate them within the system. While these beliefs to some extent are still persistent they have become less dominant because it became clear, through research, experiments and actual practice, that most experts just don't know which amount of renewable types can be integrated into the system, and through a process of trial (and actually not that much error) the percentage has now grown to several percentage points in the Netherlands. With regard to the superiority of the central, large-scale model, this is something what is often assumed as it has been the main mode of thinking in the three, four decades after the Second World War, and is entrenched in the set-up of technical education and engineering institutes (Hofman and Marquart, 2001). The advent of combined heat and power production has made a major impact to corroding this belief, although the bias of engineers still tends to be that big is beautiful.

As the advantages of a new technology are often not clear, expectations play a crucial role in the support for their development. Actors involved in innovations often try to build up positive expectations in order to gain support from a variety of actors (government, financial institutions, etc.). The role of expectations in the development of the technology depends on several characteristics (Elzen et al., 1998):

- robustness: an expectation becomes more robust as it is increasingly shared by relevant actors;
- quality: an expectation gains quality as it becomes increasingly supported by ongoing developments (proven technological innovations, collaboration between important actors);

- specificity: as an expectation becomes more specific it will become more easy to realise them because it becomes more clear what has to be done to realise the expectation (e.g. fuel cells can deliver super reliable power versus fuel cells are the power plants of the future);
- association: expectations become more powerful as they become associated with solving certain societal problems of which it is expected that the current technologies can not deal with them.

Vision building is considered another important element in a process of system change and for the renewal of organisations. As more actors develop visions regarding the way society should develop, or for a specific sub-system such as energy, understanding grows regarding the kind of (fundamental) changes that may be necessary. Vision building can be useful when there is some sort of consensus between actors that a transition is required but there is dissent on what kind of transition or on how the transition may be achieved.

The role of firms

In his dissertation Dieleman (1999) uses theoretical perspectives from technology studies and institutional economics which view innovation as a process of searching, learning and adapting to understand why it is so difficult for firms to change their routines, such as to integrate the approach of cleaner production in their organisation. The limited success of cleaner production is explained by the fact that the participation of firms in cleaner production projects does not necessarily lead to changing routines, whereas, according to Dieleman, a change in the routines of firms is central to the whole concept of cleaner production. Dieleman's focus is then on how these routines are anchored in the company and embedded in a company's context. Change processes necessary for more radical environmental innovations then need to occur both at the level of firms and their routines, and in the institutions that reinforce the way companies behave. His main conclusion is that cleaner production projects have mainly generated what he terms single-loop learning. This type of learning leads to improvements in production processes and management but does not fundamentally alter the way the company functions, or the way it manages its production process. Values, ways of thinking (beliefs) and routines are thus unchanged, and the 'art of pollution prevention' does not become integrated within the company. In order to acquire the concept of pollution prevention double loop learning is required, where underlying values and beliefs are addressed and the current way of doing things is questioned. Companies need to break through the established routines, conventions, and standards solutions and 'defreeze' established images (Dieleman, 1999: 225). Companies need to be confronted with the fact that they overlook the potential for prevention and have developed blind spots for the opportunities that exist. Confrontation is a core mechanism to break out from existing social practices. External actors often play a role in this confrontation, as they are not bound by the collective mental frames within firms. The lack of confrontation is then also explained by Dieleman because of a lack of incentives for confrontation from the firms' context. Confrontation can initially take place through networks in which companies operate. According to Dieleman, however, the composition of the networks for cleaner production are not designed from the perspective of stimulating confrontation, and also the wider context in which companies operate (e.g. regulatory environment; intermediaries; knowledge infrastructure) is not geared towards stimulating prevention, but still largely rooted in the trajectory of cleaning up pollution (e.g. pollution control instead of pollution prevention).

In the innovation literature it is often stressed how difficult it is for established, incumbent firms to develop radical, breakthrough innovations (Henderson and Clark, 1990; Christensen, 1997). Henderson and Clark (1990), for example, argue that the failure of established firms is related to the nature of innovation which is taking place, and that the distinction between incremental and radical innovation is too simple. Sometimes seemingly modest changes can have dramatic effects on established firms because of their architectural nature, implying a change in the way components in a product are linked together while leaving the core components (and the knowledge on which they are based) unchanged (p. 10). According to Christensen (1997) the failure of incumbent firms to put radical innovations in the market is because the existing market for these firms are initially not attracted to this innovation, and the company does not tend to allocate resources to technologies for which the application and value is uncertain. Christensen finds in the disk-drive industry that incumbent firms often where among the first to develop new innovative types of disk-drives, but did not really commit to them (e.g. limited allocation of resources and time relative to improving existing products). Reasons were that the product could not compete on the main markets in which their established products were sold, because of the initial poor performance (cost structure) of the new innovation, while the initial market for the new innovation (based on some new functionalities) were too small for established firms to make the turnover and profits it could reap in its main market (also because of lower profit margins). Another factor is that established firms' market research often gives the impression that customers are not really interested in the new innovation. This is however misleading, according to Christensen and other scholars, because customers need not be aware of their preferences and the new products' potential (they need to become familiar with the new product before they can appreciate it) while also the sample of customers often represents the product value chain in which the company is currently established, and not the (small group of) leading edge customers they may show some interest in the new product.

Emerging firms, on the other hand, are more willing to fully commit to and invest in the new product for which the applications and markets are highly uncertain. They are dedicated to find and create new markets and connect them to the emerging different functionalities the new product contains (e.g. for the disk-drive example (Christensen, 1997: 40), performance for mainframe computers were measured in terms of capacity, speed and performance, whereas for portable computers they were ruggedness, low power consumption, and size). If an initial market has stabilised their focus is broadened towards increasing reliability of the new product, and towards improving the convenience of the product in order to extend the market. According to Christensen, in the sequence of functionality to reliability to convenience to price, the price is generally the last factor on which basis emerging firms and their products start to compete. Christensen's main point is that when this stage is reached, the emerging firm has built up a value network[10] surrounding its product, with specific linkages with suppliers and customers and specific manufacturing and design experiences, and may move upmarket as the new product has improved its performance to a level similar or above the established product (based on its specific cost structures), with some additional functionalities and even more potential for further improvement. As these new firms and their value networks enter main markets of incumbent firms successfully, incumbent firms are often unable or too late to redesign their value networks to the new demands of the market.

2.4.4 Theorising about the role of networks in systems change

The importance of networks in innovation processes has become generally accepted. Especially when the innovation is of a complex nature, with several technologies or components involved, co-ordination of activities of actors working parallel on different technological aspects within networks is one condition for a successful innovation. Complexity implies interactions among many parts, and many interactions between the innovation and its surroundings. "*Complex technologies are those that cannot be understood in detail by an individual expert, and cannot be precisely communicated among experts across time and space*" (Rycroft and Kash, 2002: 21). As

[10] Value network is defined by Christensen (1997: 36) as "*the context within which a firm identifies and responds to customers' needs, solves problems, procures input, reacts to competitors, and strives for profit*".

technologies are complex, they require complex networks that create, acquire, and integrate the diverse knowledge and skills involved in the innovation. In a similar vein Teece (1992) argues that advanced technological systems are not created in isolation, but require building linkages for joint production of knowledge both along the supply chain, in collaboration with knowledge organisations, and with a range of actors in order to develop or adapt standards and regulations, for example industrial standards, safety regulations, etc. Van Rossum (2000) also argues that the structures of network-based industries such as electricity, transport and telecommunications, impact innovative processes in these industries. He points at the pervasiveness of path-dependent network externalities. Innovation networks in the electricity system are then strongly conditioned by the standards prescribed by the transmission network and its mode of provision.

The network perspective is a key element in the approach of environmental management, as in a system of more sophisticated environmental management the firm needs to connect with a variety of stakeholders (Roome, 1998). The focus on networks is also present in research on industrial ecology and product chains. Networks, such as in industrial ecology, are deemed crucial to advance towards sustainability as they are able to provide adaptability (e.g. continuous rethinking of goals, strategies and implementation), diversity as a learning potential (as the presence of multiple perspectives increases the likelihood of higher order learning to occur), and enable the exchange of tacit knowledge. One focus is on the organisational mode of networks and its relation to the type of innovation that is likely to be generated. Loose coupling within networks promotes radical innovation through its diversity and adaptability, but is less conducive for the exchange of tacit knowledge necessary to realise its learning potential while tight coupling is more conducive for the exchange of tacit knowledge but favours incrementalism (Boons and Berends, 2001). While the previous research focuses mainly on processes internal to the firm and its networks, in Boons et al. (2000) there is more explicit focus on the interaction between external and internal factors and processes and how this has shaped the greening of business practices in the Netherlands. Some of the 'new' organisational routines that are studied are the product-oriented approach to environmental problems (e.g. eco-design), the prevention-oriented approach (pollution prevention and cleaner production), and the management-oriented approach (e.g. environmental management systems). They conclude that although these routines have to some extent become part of the operational and management activities of companies, this has generally not resulted in fundamental changes such as radically new technologies, products, or designs. They tentatively explain this by the fact that the introduction of these new organisational routines has not been accompanied by shifts in power (changing and new coalitions) or changes in values. Dieleman (1999) also focuses on change processes in companies, and specifically addresses the question why companies seem to be captured in a trajectory of cleaning up pollution and cannot easily make the change to prevention and process integrated solutions. He explains this by elaborating how a certain way of doing things has become institutionalised in the past 30 years in problem approaches, laws and regulations, education and technology, standard solutions and so forth (Dieleman, 1999: 200). His focus is on cleaner production projects as a way to undermine this existing ‘arena’. “*Because an arena has the character of a ‘seamless web’ with numerous interwoven alignments and connections, change that is fundamental in several ways demands changes of all actors involved*” (Dieleman, 1999: 200, my translation). The framework he develops for analysing and explaining change processes in companies is based on insights from technology studies, institutional economics and evolutionary theorizing. Firms have developed certain blindness, a way of viewing problems and solutions in one particular way, which hampers prevention of pollution as firms tend not to see the opportunities available. Also, when regarding alternative solutions, these are difficult to implement due to path dependencies, as existing functional and structural connections (e.g. with the regulatory setting and knowledge infrastructure) are not geared to this type of change. He concludes that change processes rely on confrontation (unpacking blindness, make it visible, and confronting actors with other problem approaches and problem solving), reflection (analysing linkages between various levels that create path dependencies, such as the relationship between a firms’ accumulated competencies and the knowledge infrastructure), and experimenting and learning (through trial and error, opportunities and their frontiers can be assessed in a process of learning by doing, using and interacting). A partial explanation lies in the composition of the networks of the cleaner production projects which were not designed from the perspective of stimulating confrontation, and in firms’ wider context (e.g. regulatory environment; intermediaries; knowledge infrastructure) which was not geared towards stimulating prevention, had it roots mainly in the trajectory of cleaning up pollution (e.g. pollution control instead of pollution prevention). The observation of Boons et al. (2000) that the more top-down oriented approach of stimulating environmental management dominated the more bottom-up oriented pollution prevention approach is also very relevant. The environmental management approach is much more oriented towards providing environment relevant information and much less on redesigning and improving production processes and products. In that sense it fitted better to the regulation approach, policy style, competencies and routines of permit givers and inspectors who are able to judge whether the delivered information is appropriate but much less so whether a production process could be significantly improved.

2.4.5 Theorising about the role of institutions in systems change

However useful the analysis of networks this needs to be accompanied by a larger framework that explains evolution and change in networks. Networks are shaped in processes of co-evolution, for example, they co-evolve with their technologies, in the sense that networks shape the processes of innovation and the evolving technologies shape the networks. Our interest is mainly in the underlying mechanisms that can explain the direction and speed of these processes of co-evolution. The role of institutions and rules is central to these mechanisms: institutions explain how technologies are handled and productively used, i.e. every technology comes with a certain recipe, division of labour and mode of coordination (Nelson, 2002).

Institutions can be seen as pieces of fabric that solidify certain ways of doing things and the nature of interactions between actors. These pieces of institutional fabric develop with technology and their networks in a process of co-evolution. Institutions are part of every day's activities of actors, e.g. when taking a used bottle back to a supermarket there are institutions in place to make sure that deposit money is returned and that the bottles are re-used (such as agreements between a variety of companies, laid down in contracts, with some kind of punitive scheme in case of defection). Essentially, these institutions have developed to routines and we don't have to ponder over this every time we go to the supermarket. The nature of institutions can also create formidable barriers for the introduction of new innovations, especially when these require the creation of new linkages between actors, networks and technologies, and ultimately the creation of new routines. Walker (2000) introduces the term institutional entrapment to explain the difficulty to get out of the nuclear trajectory because of the embedded institutional, technological and economic commitments.

While institutions play an important role in providing stability to existing systems, patterns of institutional change may provide the basis for processes of systems change. A sociotechnical system consists of various elements that are aligned and woven together. Institutional changes that represent change in the way an element is structured in the system is followed by adaptive changes in other parts of the system. In essence it is thus possible that a sequence of changes is set into motion that may erode the institutional structures that contribute to the system's functioning and the underlying practices and may give rise to new ways of doing things.

2.5 Concluding remark

This chapter has taken stock of a number of theoretical perspectives relevant for the analysis of systems change. We started from two perspectives, one focussing at theories of innovation and technological change and another assessing institutional theories and their theoretical contribution to systems change. A first conclusion is that innovation oriented theories increasingly integrate institutional aspects into their perspectives in order to explain processes of innovation. Especially for the understanding of more fundamental systems change the role of changing interaction patterns and rule systems are more and more perceived as co-evolving with technological change. A second conclusion is that institutional theories can contribute to the conceptualisation of systems change based on the co-evolution of institutional and technical change. In the following chapter we will build upon these insights and develop a conceptual framework for the empirical part of the book.

Chapter 3

Analytical framework

3.1 Introduction

This chapter introduces the analytical framework that will guide the following empirical chapters. The focus is on the way systems and their dynamics can be studied. Central to this book is the hypothesis that transformation of systems of production and consumption involves a multi-level process of co-evolution of institutional and technological change. At the micro level it involves the development of a novel or alternative practice, such as a new product, technology or concept, made possible as a variety of actors, such as firms, policy-makers, customers, change their way of doing things. At the meso-level it involves changes in practices at the level of sectors, such as the formation of industrial, technological and management standards, and new forms of exchange and interaction between a variety of actors, and at the macro-level it involves changes in systems of innovation, regulation and the way the system is embedded in society. Systems change slowly occurs as changes at different levels start to connect and synchronise, leading to the emergence of new institutional fabric that solidifies linkages between the different levels.

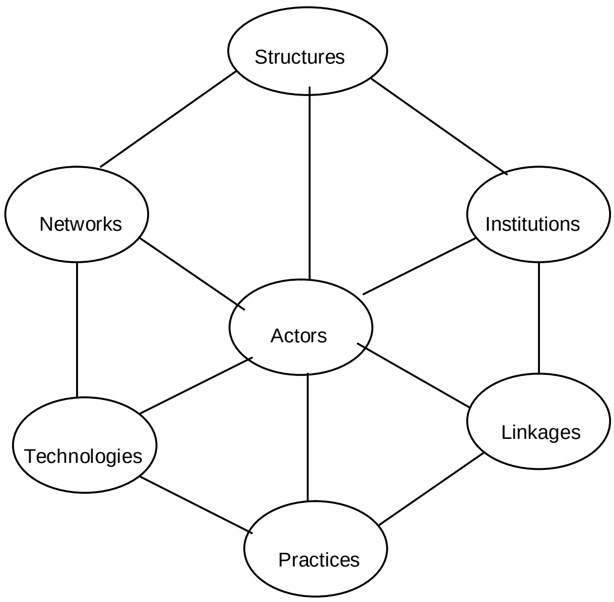
The aim of this book is to test and further specify this general hypothesis by analysing patterns of change in the electricity system. Scientifically, the relevance of the book is in its analysis and explanation of fundamental processes of change, a topic relevant for a range of scientific disciplines, from economics, sociology, technology studies, to policy science. Its societal relevance lies mainly in its use for gaining insight in the way systems change can be directed towards the normative goal of sustainable development.

The chapter introduces an institutional perspective on systems change which will be applied in the empirical chapters. The next section introduces this perspective, the way it is operationalised through key elements of sociotechnical systems, and the way these systems are embedded in broader society. A further section introduces the multi-level perspective on systems change as a second perspective that is utilised in this book.

3.2 An institutional perspective on systems change

Fundamental change in the electricity system will imply the emergence and spread of alternative technological and organisational forms in the larger context of the electricity system. The connection between technological and organisational form is a crucial one. The implication is that the way technology is handled, applied and used is related to various modes of organisation and coordination, such as the way various technologies and components are related to each other, procedures regarding the way the technology is handled, and division of labour regarding various levels of operation for the technology. Our conceptualisation of sociotechnical systems is presented in Figure 3.1 and simply consists of seven interconnected key elements.

Figure 3.1 Key elements of sociotechnical systems: the LASTPIN approach



Key elements of systems: the LASTPIN approach

The starting point in the analysis is the existence of contemporary systems of production and consumption in which activities and decisions of actors are guided and constrained by the way the system is configured through linkages between multiple dimensions and multiple levels. The multiple dimensions we turn to later are located in areas of knowledge, policy, the market, and society. The multiple levels include the level of actors, networks, technologies, and practices, the sociotechnical system level, and society and its structures. This conceptualisation builds upon the multi-level and regime perspective developed by Rip and Kemp (1998) and others, but diverges as societal structures are introduced as a separate level. In the work of scholars on transition theory, the landscape level has been conceptualised rather weak as a set of diverse external factors, such as oil shocks, wars, but also cultural values and broad political coalitions (Geels, 2004a: 34). We do not argue with the idea that real external factors, such as oil crises or climate change, put pressure on regimes, but contend that the way pressure is put on the regime takes place in a translation process within the wider societal structures in which the sociotechnical system is embedded.

Let us return to our *LASTPIN* approach and introduce the core elements of actors, technologies, practices, and networks[1]:

Actors, their behaviour, underlying objectives and beliefs, competencies, and resources, on the one hand are conditioned and constrained by existing systems but on the other hand shape the way systems develop, and some actors may act as prime movers in the shaping of alternative paths and, eventually, new systems. Actors are central in establishing and changing systems, as decisions, activities, investments and strategies of actors determine the way the system develops. Essential in our understanding, based mainly on insights of evolutionary thinking, is the role of routines in the behaviour of actors (individuals but also organisations). Routines are based on acquired competencies, accumulated experiences, and learning, and it is difficult to re-learn or de-learn towards other routines. Humans develop routines to guide daily activity, but firms also develop routines in their management and production, and for the evaluation of investments or technologies. Frames of reference are developed based on accumulated experiences, and involvement in alternative practices (including technologies) requires de-routinising and reflective behaviour. As know-how, routines, decision rules and dominant competencies are relatively invariant, this gives rise to dominant designs, technological regimes and paradigms (Saviotti, 1996: 45). This culminates in the establishment of belief systems shared by coalitions of actors, with certain problem

[1] The process of formation of these elements was further inspired by the work of various scholars on technological systems and innovation processes, such as Kash and Rycroft, 1999; Van de Ven et al., 1999; Carlsson et al., 2002; Jacobsson and Johnson, 2000; Berkhout et al., 2002; and Arentsen 2002.

perceptions and solution paths. There are similarities with the concept of belief systems developed by Sabatier, but here the roots of the belief system is strongly linked to developed routines and accumulated experiences and to the dominant design of the technological system, and less to norms and values that form the deep core beliefs in Sabatier advocacy coalition framework (Sabatier and Jenkins-Smith, 1993). Here the belief systems involve ideas about configurations that are expected to work, about the directions knowledge has to develop, and about societal acceptable and market viable practices. Our analysis will focus on the way routines and belief systems have developed in the electricity system, and through what mechanisms they change. In the more specific case studies the focus is on alternative practices that were developed within the electricity system. The aim is to analyse to what extent the emergence of these alternative practices was related to changing routines and belief systems, and to explain how these changing routines and belief systems were brought forth. There the focus is also on the role of (changing) networks, new technologies, changing linkages and institutions in that process.

In ***networks*****,** different actors meet, interact and collaborate in order to safeguard interests, to realise goals and objectives which can not be achieved independently, and to exchange information, knowledge and resources. Thus networks are necessary to enable, facilitate, and align activities of actors and also function as platforms for solving problems a system faces, for establishing the principles under which technologies function (e.g. standards), for guiding directions of R&D (by shaping beliefs and expectations on the promise of technologies), and for the creation of new technological paths. Our interest lies mainly in understanding the role of the nature of networks for the type of practices that are developed. Networks may be conducive for initiating systems change as they are able to provide adaptability (e.g. continuous rethinking of goals, strategies and implementation), diversity as a learning potential (as the presence of multiple perspectives increases the likelihood of higher order learning to occur), and enable the exchange of tacit knowledge. One focus is on the organizational mode of networks and its relation to the type of innovation that is likely to be generated. Loose coupling within networks promotes radical innovation through its diversity and adaptability, but is less conducive for the exchange of tacit knowledge necessary to realize its learning potential while tight coupling is more conducive for the exchange of tacit knowledge but favours incrementalism (Boons and Berends, 2001). Another aspect is the composition of the network, with homogeneous networks (actors with similar interests, backgrounds) may be more goal-oriented, while heterogeneous networks may provide more ideas for alternative practices, and profit from linkages to other networks, but will be more difficult to organise and maintain its momentum.

Technologies and their artefacts form the material part of a system, with a variety of technologies and technological components making up a technological system. The way technologies and their components are linked in a technological system is a focal point of attention as for example the specific architecture or a dominant design guides and constrains the evolution and uptake of technologies within a system. The technologies, components and their underlying principles, problems are also part of knowledge fields that play a role in guiding further search processes, problem definitions (reverse salients) and solution paths. With regard to systems change, the focus is on alternative technologies that have the potential to change the system, and potential paths that may lead to transformation or renewal of systems. Key notions are the flexibility, versatility and linking potential of technologies. As a technology is more flexible and versatile it has a larger chance to connect to the dynamics in systems and society at large (e.g. it can be used because it can connect to the development of the new economy plus the demands for more sustainable behaviour).

Practices refer to the way things are done through involvement of a variety of actors, technologies and networks. It can range from standard practices done by actors within the system, alternative practices by actors not 'captured' by or breaking out of the system, and the introduction of novel practices. The focus is here on the nature of the practices (standard, alternative, new) and on the actors (routines, competencies, motivation, power), networks, technologies, and linkages playing a role in making the practice work. With regard to the existing pool of practices we analyse how these are supported by institutions, powerful actors, linkages between different components and technologies, and relationships between different actors. Systems change can be seen as a sequence of alternative and new practices that are set in motion. Understanding why certain practices may move on towards further diffusion and others not is key to this. The diffusion literature may give some clues, but the main limit of the work of Rogers (1995) is that it does not take into account the way these practices co-evolve with markets, users, and institutions. Rogers conceptualizes diffusion as the introduction of a finished innovation into markets, whereas our focus on practices takes into account that the nature of the practice is constantly shaped by actors, in processes of imitation, adaptation, and reconfiguration.

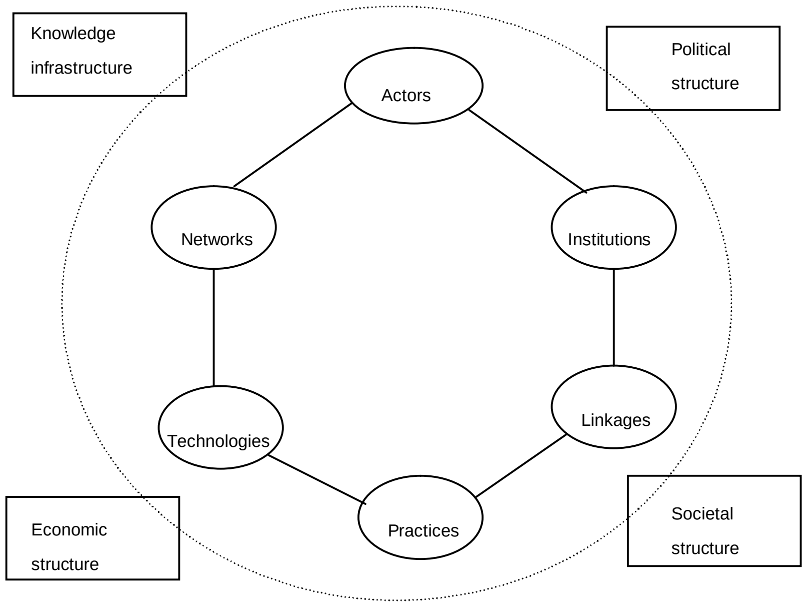
While these elements form the building blocks of any system of production and consumption, the way they are configured and fine-tuned in their development is explained by the following components of systems:

Linkages involve connections between different components of the system. This may involve relationships between actors such as buyers and suppliers, government and business; between actors and technologies with certain actors developing or using specific technologies; and between technologies, as products contain a multitude of technologies that work together and may involve several knowledge areas. Practices contain linkages between actors, technologies and networks. Alignment is a core mechanism in the development and stabilisation of systems. It refers to the way actions of actors become tuned to each other through the emergence of an established design, through the emergence of a division of labour for various actors in the system, through the emergence of standards, through shared problem definitions and shared visions regarding the ways of improvement for, and the future direction of, the technological system. Understanding and identifying the processes through which alignment takes place, such as interaction processes in different networks and fora that are bound by the knowledge and principles that are generally accepted within them, is a key task necessary to understand the stability of systems and opportunities to corrode this stability. In this corrosion of stability and in the shaping of alternative paths confrontation is an important mechanism. Confronting actors with other problem definitions, problem approaches and solutions can increase their receptiveness to think beyond the established ways of doing things.

Institutions form the 'rules of the game' in the organisation of systems of production and consumption. They include formal rules such as market rules on profits, property rights, patents, liability, planning, and investment decisions, and informal rules such as those regarding principles of trust, negotiation, and co-operation. Institutions confirm ways of doing things, and enable them to be done in a routine manner, as they facilitate minimisation of transaction costs (search for information, contractual aspects, etc.). Our analysis of institutions starts from the recognition that a layered pattern of institutions exists. This ranges from fundamental ground rules regarding the organisation and co-ordination of societal processes, to more specific rules that can be located in the different dimensions of the system, to even more detailed rules concerning specific linkages in systems. Apart from being multi-level, the relevant institutions in systems are also multi-dimensional. The key to understanding systems and systems change is to gain insight in the nature of the institutions that align development between those levels and dimensions.

Structure involves the way the different elements are configured and ordered into the system, and especially the way sets of institutional arrangements have become structural in the interaction of the sociotechnical system with wider fields of knowledge, policy, economy, and society. Outcomes of these interaction processes lead to structural elements such as a particular industrial organisation, knowledge infrastructure, policy organisation, and material infrastructure. A central point we make therefore is that sociotechnical systems, such as the electricity system, are embedded in larger societal structures such as the knowledge structure, economic structure, political structure, and societal structure (the dimensions we referred to earlier). This is illustrated in Figure 3.2. These are not fully external structures, as continuous processes of mutual adjustment between the sociotechnical system and the broader societal structures are underway, such as the translation of public goals to strategies of actors within a system, and a focus of public funds (R&D) towards needs of the system. Table 3.1 provides basic aspects of the linkages of these wider societal structures to sociotechnical systems of production and consumption.

Figure 3.2 Sociotechnical systems embedded in wider societal structures



Together, in a re-ordered sequence, they form the so-called *LASTPIN* approach, with the name also indicating how changing the last pin in the system may start a sequence of changes through all elements that can ultimately lead to transformation of a system of production and consumption.

Table 3.1 Typology of linkages of production-consumption systems to wider societal subsystems

1) Economic system - mode of coordination - industrial organisation - mode of provision - perception of nature of problems – solutions
2) Knowledge infrastructure - mode of coordination - mode of organisation - perception of nature of problems – solutions
3) Policy system - mode of coordination - organisation of policy - mode of communication - relation to political, societal goals - perception of nature of problems - solutions - R&D policy and orientation
4) Society - mode of coordination - mode of communication - perception of nature of problems - solutions

Key processes of systems dynamics

After having introduced the conceptualisation of sociotechnical systems and its key elements, we focus on the way processes of change are conceptualised. A first concept we use is that of institutionalisation. With regard to institutions we follow the definition of Scott (2003: 880): "*Institutions are social structures that have attained a high degree of resilience. They are composed of cultural-cognitive, normative, and regulative elements that, together with associated activities and resources, provide stability and meaning to social life*".

Institutionalisation refers to increasing coordination of activities through institutions of a regulative, normative and cognitive nature (Zucker, 1988; Holm, 1995; Scott, 2001). High institutionalisation implies that a certain way of doing things is taken-for-granted and embedded in regulative and normative institutions. An example is the way every house in the Netherlands is connected to the electricity grid, and provided with electricity sockets. This is taken-for-granted by both house owners as those involved in planning and building houses. But, as we will show in the coming chapter, this was not taken for granted in the early 1900s. Through a process of normative (societal goal of access to electricity for everyone) and regulative (withholding concessions if not everyone was to be connected) institution building every household became connected, and electricity became taken-for-granted. Important is the realisation that this process of institutionalisation could be successful because it had acquired legitimacy within society (convenience and low cost of electricity), within government (electricity growth as a means for economic growth), and within the economy (electricity as effective and low-cost power source).

Our focus is especially on the interplay between changes in practices (innovations) and institutional changes. A main premise is that changes in practices can only become durable and significant (in the sense of representing a form of systems change) if they are accompanied by institutional changes that act as carriers of the new practices. Simply stated: innovation and institutional change are two sides of the same coin of systems change. With regard to institutions we use the idea of a hierarchy. This implies some kind of nested system of sets of practices guided by sets of institutions, and activities aimed to change those institutions, such as proposed by Holm (1995). We feel this distinction is valuable, because it represents two totally different playing fields, comparable to playing chess at the chessboard on the one hand, and trying to change the rules for chess within a rule-making body such as the FIDE[2] at the same time. Apart from discerning between practices guided by institutions and practices intended to manipulate institutions, we also distinguish institutions that represent ground rules (or fundamental rules) and specification rules that specify, and built upon, ground rules, inspired by, among others, Coriat and Weinstein (2002). Creating a level playing field within European electricity systems in the wave of liberalisation in the 1990s and 2000s may be considered a ground rule, and the rules under which mergers may exceed acceptable levels of market shares in defined areas as a specification rule.

Furthermore, we contend that dominant practices organised in sociotechnical systems gain stability as a certain ‘institutional logics’ becomes prevalent. In other words: a particular institutional logics shapes practices, exchange relationships, and structures. We define institutional logics as a set of socially constructed assumptions, values, and beliefs (Sine and David, 2003:

2 International Chess Federation.

185). Institutional logics are related to institutions but transcend them in way that they form a sublimation of sets of institutional practices related to a system. Institutional logics synchronise action within production and consumption systems, and are also based on synchronisation of the linkages with broader systems in society. These linkages are also crucial as they also function as carrier and creator of different types of legitimacy that are essential for the functioning of the system as a whole and especially for maintaining the institutional logics that underlie them. The association of low-cost electricity provision with expansion of central power stations, and electricity consumption increases with economic growth and progress is an example of such institutional logics which was crucial for the expansion of the electricity system. Various actor groups provided legitimacy for the logics, as each group was being able to define institutional logics as being congruent with their own motives, goals and values.

A highly institutionalised system of production and consumption furthermore locks out alternatives based upon different fundamental principles and alternative linkages to knowledge, economic, policy and societal fields. Basic principles of path dependence are at work here, but also more cognitive aspects such as that alternative are either not considered, not taken seriously (what we have works fine and we are not sure the alternative will work) or exhibits a serious mismatch with the principles and components of the existing system.

Several processes are then necessary to start the search for alternatives and to further develop potential alternative. It can occur if the existing practice does not continuously reconfirm established institutional logics, e.g. when electricity consumption growth is no longer matched by low-cost electricity provision (Hirsh, 1999). In the institutional literature the role of disruptive events, or external shocks, is also seen as an important source for de-institutionalisation and erosion of dominant institutional logics (Meyer and Rowan, 1977; Hoffman, 1999; Sine and David, 2003). Such events may trigger the search for alternatives. Through rethinking of existing routines, modes of organisation and coordination, alternative previously rejected may come under consideration. But often, and also in the case of the electricity system, alternatives are either not mature enough and do not match the existing system.

Depending on the nature of the technology and its intended application, integration of an alternative technology in an existing system involves some level of adaptation and alteration of the existing modes of organisation and coordination. The integration of such an alternative form within an existing system is more than a straightforward diffusion process where superior characteristics lead to selection of the alternative at the expense of the existing form. It involves learning regarding the technology and its matching organisational form, changing interactions and linkages, the build up of new competencies, and the build up of legitimacy and trust regarding the functioning of the new alternative and its proponents. Thus the success of alternatives therefore also depends on processes of institutionalisation.

Such a process of institutionalisation of an alternative can only be successful if it is accompanied by a process of re-institutionalisation of existing dominant technological and organisational forms. De-institutionalisation refers to erosion of an institutionalised activity or practice (Oliver, 1991: 563). Re-institutionalisation refers to adaptation of existing ways of doing, organising, and coordinating to allow an alternative form to emerge and expand. Rules, both formal and informal, need to be re-considered, re-negotiated, and changed in order for the alternative to take root. The focus of the empirical chapters is on tracing these patterns of institutionalisation and re-institutionalisation and the forces that influence these patterns in order to be able to explain the evolution of alternative electricity paths.

3.3 A multi-level perspective on systems change

A further inspiration for the analysis in the empirical chapters is the work of the scholars on transition theory (Kemp, 1994; Kemp et al, 2001; Verbong, 2001; Geels, 2002ab; Elzen, Geels and Hofman, 2002, 2004; Geels, 2004; Raven, 2005). Based on their work and own involvement in projects where these ideas were applied (Hofman and Marquart, 2001; Hofman, Elzen and Geels, 2004), we start from the following notions.

First, transitions always involve changes at multiple levels and interactions between multiple levels. Processes of change will only acquire a transitional nature as they take direction and gain momentum through interlinkages between landscape developments, regime changes and niche emergence. We aim to illustrate to build scenarios originating from a potential selection factors, variations, and couplings. We aim to indicate aspects of uncertainty and the degree of robustness of certain changes, starting from the presumption that change processes are likely to occur when a number of conditional factors come together (the idea of tipping points[3]). Important in these processes of change is that they represent change of the direction and velocity of the system, which is difficult since the system has a lot of mass, machines, infrastructures, etc. in which considerable capital has been

[3] A popular account of the idea of tipping points is provided by Gladwell's (2000) book. See also Urry (2004) for an application to car-based transport.

invested (Hughes, 1983). Apart from these tangible aspects the focus is on intangible aspects, such as the mental models or belief systems to which the regime is associated.

Second, transition processes involve sequences of changes with the essence of the change being the formation of (qualitatively) new couplings that may exploit various developments at landscape, regimes and niches, where an initial change in one dimension triggers wider change as actors react and adapt their decisions and strategies in a significant way. It involves not only diffusion but also qualitative changes. An obvious example is policy change such as the initiation of a new policy approach that may trigger reactions within business, civil society and so forth. Examples are the zero-emission scheme for cars that was started in California, and led to significant changes in strategies of major car producers, and to reorientation of R&D directions for public and private organisations. Maybe this change process was limited because this was not followed by similar programs in other regions and because the major car producers also started a line of defence to reduce the radical nature and impact of the policy program. In the case of transitions the sequence of change lead to a process of chain reactions where waves of change tend to spread more and more and become pervasive throughout society. Often this then involves parallel processes of change that together provide strong momentum for change. An example is the introduction of the computer and the way it has transformed the processes of information provision and transport, and changed behaviour of people and businesses regarding work, trade, leisure, communication, etc. But this is also affecting more traditional regimes such as electricity and transportation and may provide gradients for transitional processes there.

This implies two lines of focus for our research. First there is a need to indicate which type of changes or events are plausible to trigger the sequences of change just mentioned. Where may they start and how do they offset these waves of changes which will resonate strong and long enough to trigger significant processes of transitions? What kind of parallel changes may tip the change process towards accelerating?

Second, it implies some indication regarding the reactions that certain events, actions or changes may provoke, and the second and third waves of reactions to the earlier ones. Such a ‘model of change’ may lead to the surprising and unexpected outcomes that are often typical of transitions and deviates from models that are based on extrapolations or on first reactions to certain changes, such as new policy approaches that are initiated. A straightforward example of a sequential pattern of change is the so-called domino-effect where an initial move of one business or government to invest significantly in a particular kind of technology or to launch a prototype of a particular product is followed by others as their strategies influence each other and actors don't want to run the risk of falling behind, accelerating the development of the technology (Geels, 2002a).

Third, Geels (2002a) identified two basic patterns in transitions, one in which the transition is initially niche and technology-led and then broadens, and one in which the transition is triggered by increasing tensions within regimes, triggering institutional change where multiple technologies hook on to. Geels (2002a) has labelled these two patterns technical substitution and broad transformation. The purpose here is to focus more specifically on the role of institutional changes within patterns of transitions and to identify and specifcy the nature of institution-led transitions.

3.4 Methodological aspects

The research design is a longitudinal study combined with multiple case analysis of change in the electricity system in the Netherlands. The electricity system has been chosen because it is a major contributor to the climate change problem specifically, and more general a part of unsustainable development (see chapter one). The focus is on the Netherlands, but when relevant linkages with other countries are taken into consideration. Also in the empirical part comparisons will be made with experiences in a variety of countries to gain more understanding of the dynamics of change.

In the empirical analysis we identify alternative routes taken within and outside the electricity system in the past thirty years. A first step is to document the emergence of new technological and organisational forms and to explain their emergence. A second step is to analyse the dynamics that underlie relative success or failure of further extension of the routes. This also involves documenting and explaining processes of institutionalisation of new technological and organisational form and the way these interact with and processes of de- and re- institutionalisation within the dominant technological and organisational forms of the electricity system. In a final step, two cases where remarkable dynamics took place have been chosen for in-depth analysis.

Data collection and analysis has been based on a triangulation strategy. Primary sources include data on technological and institutional change in the electricity system. Secondary sources include both theoretical and empirical work on technological change, institutional change, and systems change. Thirdly, interviews have been conducted with principal actors in, and analysts of, the electricity system using semi-structured, open-ended interviews.

Chapter 4

Stability and transformation in the electricity system[1]

Explaining success and failure of paths taken

4.1 Introduction

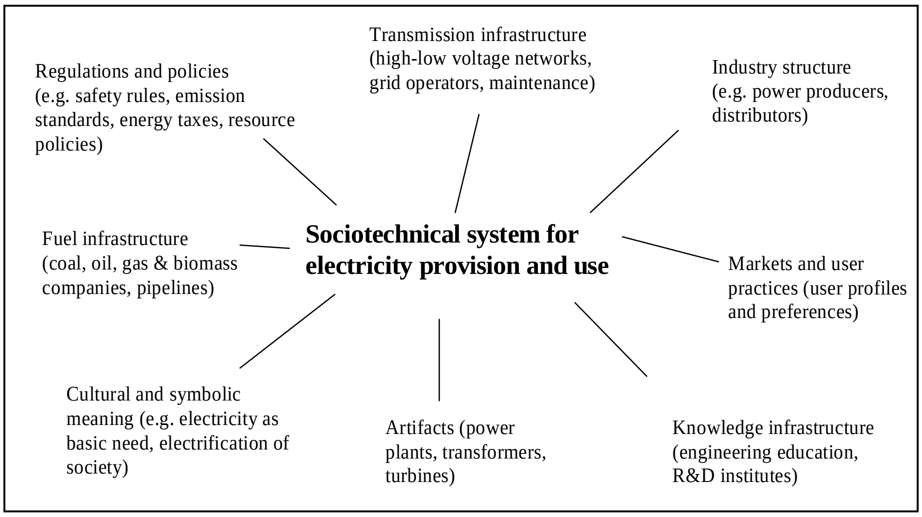
This chapter characterises main structural changes that have taken place in the electricity system in the past three decades. The purpose is to interpret and explain the main dynamics in terms of interaction between technological and institutional change. More specifically the aim is to understand the nature of a range of paths taken in the past decades as dynamics either being dominated by lock-in and path dependence, or as representing the formation of a new path in which processes of escaping lock-in take a central role.

The electricity system has often been characterised as a large technical system based on several components and technologies connected to each other in a way that makes it difficult to switch to fundamentally different technologies or to alter the design of the system (Hughes, 1983, 1987). Within this perspective promising new technologies are not taken up because this would require changes at other components and technologies due to a misfit with the existing design of the electricity system. More recently authors have broadened this perspective by also including features of 'lock-in' at and between other dimensions, such as economic, infrastructural, social, cultural, and regulatory (Martin, 1996; Unruh, 2000). Thus, while monopolistic organisation enabled fast expansion of the electricity system by locking in to a path of up scaling steam turbine technology and connecting the countryside to the grid in the first half of the twentieth century (Hughes, 1983; Nye, 1990; Verbong, 2000), it effectively locked out alternative energy technologies that were emerging in the 1970s and 1980s due to

[1] Most data for this chapter were gathered in the framework of the MATRIC project: Management of Technology Responses to the Climate Change Challenge, see Dolfsma et al (1999), Arentsen and Eberg (2001), Hofman and Marquart (2001), Moors and Geels (2001) and Von Raesfeld et al (2001). Support for the initial research by Hofman and Marquart (2001) by the Dutch National Research Programmes on Global Air Pollution and Climate Change (NRP) is gratefully acknowledged.

energy saving and efficiency considerations but required fundamental changes in the configuration of the electricity system and its underlying principles. In this perspective the electricity system is conceptualised as a sociotechnical system consisting of a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks, and supply networks. Figure 4.1 gives different interconnected elements for the system of electricity provision and use. The elements in a sociotechnical system have become aligned, fine-tuned and woven together through processes of institutionalisation. Institutionalisation refers to increasing coordination of activities through institutions of a regulative, normative and cognitive nature (Zucker, 1988; Holm, 1995; Scott, 2001).

Figure 4.1 Sociotechnical system for electricity provision and use



Our analysis of changes within the electricity system in the past thirty years focuses on identifying a number of alternative routes taken, identifying the nature of change in practices these represent, identifying the extent to which they represent changes in institutions, and aims to gain understanding in the nature of their interaction with patterns of institutional change.

The organisation of this chapter is as follows. First we focus on the origins of the electricity system in order to understand the way the system came into being and the nature of institutionalisation through which the system became embedded in society. Secondly, we describe how different patterns of change emerged both from within and outside the regime. In a final section we draw overall conclusion based upon the analytical concepts presented in chapter three.

4.2 The origins of the system

It is beyond the framework of this thesis to present details of the early development of the electricity system, but based on studies on the evolution of electricity systems in the USA (Devine, 1983; Hughes, 1983; Granovetter and McGuire, 1998; Hirsh, 1999), the UK and Germany (Hughes, 1983), and the Netherlands (Verbong, 2000), we present an analytical overview of main patterns of change. We aim to explain why in a situation of diversity of technological and organisational forms one particular design became dominant. This historical analysis bears relevance as in the early twenty-first century increasing diversity of technological and organisational forms is emerging relative to the central station electricity system based on fossil based turbine technologies.

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). Edison strongly advocated, and invested in, the central station electricity system, with electricity as primary commodity produced in central power plants and distributed to a variety of users (Granovetter and McGuire, 1998). While ultimately the central station model became the dominant design throughout the developed world with its height in the post-war period of steady economic growth, in the early period of the electricity system there were several technological and organisational forms competing. Isolated plants initially were dominant, according to Verbong (2000) for example, in the Netherlands 80% of installed capacity in 1895 was by self-producers[2] with the share dropping to 60% in 1912. Similarly in the US by 1902 half, and by 1912 more than half, of electricity production was generated in isolated plants in individual apartment buildings and factories (Granovetter and McGuire, 1998). Central station electricity systems started to increase as different uses for electricity developed apart from lighting, such as power devices and traction, and the larger scale central station systems could more efficiently supply electricity through obtaining a higher load factor (Hughes, 1983; Verbong, 2000). There was also a mix of privately and publicly owned plants, and both alternating and direct current systems existed.

[2] The term self-producer is used to refer to companies that generate electricity for their own use.

In their analysis of the emergence of an US electricity industry Granovetter and McGuire develop the argument that the emergence of a rather uniform set of technologies and organisational forms should be explained from the influence of a social network centred around Samuel Insull, initially secretary and executive to Edison and from 1893 president of the Chicago Edison Company (Devine, 1983: 354), which dominated the two electricity trade associations[3] (Granovetter and McGuire, 1998: 153-154):

> "*Insull's circle, their firm associates, and their AEIC supporters presented papers advocating the elimination of isolated systems and the integration, centralization and state-level regulation of production. They influenced the content, agenda, and goals of (both sets of) trade association committees toward load building and balancing and other "growth dynamic" attributes. They also actively promoted the reconfiguration of suppliers and dependent downstream constituencies to match those 'emerging trends'.*"

In the account of Granovetter and McGuire the emergence of dominance of the central station electricity system is about entrepreneurs who developed and shared a vision on the central station system and its necessary growth dynamics, such as Edison and Insull who mobilised all their resources, and those of others, in the expansion of central station electricity systems and in making other options appear unattractive, and spanned boundaries between different actors such as firms, regulators, bankers and politicians in developing a collective vision. In many cases, however, other options such as isolated, neighbourhood, decentralised and multi-purpose systems were viable or even more efficient in specific circumstances. These systems were increasingly frustrated in their operation as they had to overcome regulatory bodies that increasingly decided against decentralised alternatives, had difficulty in acquiring licenses and equipment because of lack of competition between equipment producers, and had to comply with 'bureaucratic' regulations that favoured central station electricity systems (Granovetter and McGuire, 1998: 164-165). In essence the organisational and technological forms propagated by Edison and Insull cum suis became more and more institutionalised, with fora for exchange of knowledge and information such as the trade associations dominated by pro-Edison opinion leaders and biased towards central station electricity systems, and with regulations tended to gear to central station systems while foremost hampering decentralised systems. The Edison-Insull actor group was successful in spreading a specific interpretation of electricity with regard to the nature of the system of production, distribution and uses, and to the division of the different tasks within the system. This predominantly locked out several

[3] The Association of Edison Illuminating Companies (AEIC) was formed in 1885 by Samuel Insull in response to the formation of the National Electric Light Association (NELA) earlier that year (Granovetter and McGuire, 1998).

actor groups, who represented different interpretations with regard to the nature of the system and its organisation. The Edison-Insull interpretation also started to structure activities of actors in fields relevant for the electricity system, such as directions and agendas of R&D in the knowledge field and regulations related to the electricity system in the policy field.

Hughes' (1983) account of the evolution of electricity systems in the US, the UK and Germany has been rather influential viewing large technical systems as sociotechnical systems driven by co-evolution of social and technological change. Hughes illustrates how electricity systems evolve distinctly across countries as rather similar technologies become embedded differently in various contexts because linkages between technical, industrial, juridical and political aspects take different forms. His main purpose was to find out how these systems are able to seemingly expand in a coherent fashion, or in other words how these systems find direction and stable growth paths. He argued that systems find direction and gain stability because general principles emerge that become shared by actors in the system. As long as adoption of these principles leads to satisfactory effects in terms of efficiency improvement and/or expansion these actors are likely to stay in tune with these principles if no major changes in circumstances occur (Hughes, 1987: 76, 79). The following principles became generally accepted as the central station electricity system matured from the 1920s on (Hughes, 1983: 370-371):

- Obtaining economies of scale with large generation units such as steam and water turbines;
- Massing generating units near load centres of economical sources of energy and near cooling water at giant power plants;
- Transmitting electricity to load centres through high voltage transmission lines;
- Cultivating mass consumption by charging low and differentiated rates allowing supply to create demand;
- Interconnecting power plants to optimise their different characteristics;
- Interconnecting loads to take advantage of diversity and thereby raising load and demand factors;
- Centralising control of interconnected loads and power plants by establishing dispatching, or system co-ordinating centres;
- Forecasting load requirements to achieve optimum operations within the interconnected system;
- Lowering installed and reserve capacity and co-ordinating maintenance shutdowns through the exploitation of power plants interconnections;
- Accepting governmental regulation to establish a natural monopoly;
- Earning a regular and adequate return on investment to obtain capital at a reasonable interest.

Hughes' basic model of change of large technical systems focuses on two main dimensions. The first involves the way the system interacts with external or contextual changes and the second the way the system solves internal problems that hampers system expansion. These reverse salients, as Hughes labelled them, can be solved if actors collectively perceive a specific problem as the major bottleneck and if their activities are mobilised in overcoming this reverse salient. Actors with a leading role within the system, such as a system builder as Edison, may be able to translate reverse salients into critical problems that become shared by other actors, while boundary spanners such as Insull play an important part in the diffusion of these ideas. Apart from the more technical and legal principles listed above it is thus possible to add another, more cognitive, principle of sharing similar ideas about the nature of the problems within the system and the way they should be solved.

Verbong et al. (2000) account of the evolution of the Dutch electricity system shows how Dutch municipalities and provinces strengthened their grip on electricity supply by opening public facilities and refusing concessions to private companies. This process ran parallel with increasing economies of scale made possible as investments in steam turbine outran steam engines and as alternating current was increasingly adopted for larger distribution networks. Electricity supply thus increasingly took the form of a natural monopoly and was dominated by initially municipal and later provincial stakeholders.

The way in which electricity consumption developed and was cultivated is another crucial part of the transition towards an electricity system. Households had to become used to electric lamps, a rather different practice than using oil or gas lamps, although generally quickly considered more convenient due to the invention of the incandescent light bulb by Edison in 1879. Electric trams replaced horse trams, and manufacturing companies shifted from steam and water engines to electric motors as their source for mechanical drive. In an analysis of the shift from steam to electric power in US manufacturing Devine (1983) reports how initially electric motors were used to replace steam engines without changes in the organisation of production. At the end of the 19th century steam engines were the main source for mechanically powering machines. The first use of electric motors in manufacturing plants was in 1884, in 1900 the share of electric motors as a source for mechanical drive was about 3%, in 1910 around 20%, in 1920 over 50% with electric motors replacing steam engines as the main source for mechanical drive, and in 1929 78% of total capacity for mechanical drive was based on electric motors (Devine, 1983: 349). At first instance substitution took only place in those cases where replacing steam engines by electric motors for driving machinery reduced direct costs. As companies found out that indirect benefits are often more significant, contributing to a significant rise in productivity, especially when accompanied by changes in the production process. Electric power turned out to be less error-prone and more flexible. Especially when the line shaft system, where machines were driven mechanically by a central power source through a complex system of shafts and belts, was replaced by electric group drive and later electric unit drive, electricity could serve as a lever in production. These new practices were also actively promoted by the Edison oriented utilities as it fitted their growth dynamic vision. Detroit Edison, for example, was lending motors to manufacturing plants in combination with free energy services to ensure proper installation and higher productivity and to safeguard expansion of electricity consumption (Devine, 1983: 370). Crucial was that electricity was perceived in a different light, not as part of the existing ways of doing things, but as enabling new, more efficient and more productive practices. According to Devine (1983: 372): *"a fundamental change in viewpoint preceded and accompanied exploitation of the unique flexibility of electricity in production"*, a change in belief that, at the turn to the twentieth century, was increasingly voiced by leading engineers, academics and entrepreneurs. Thus, experiences and learning within companies, the translation of these experiences into new configurations of technologies and organisation of production, and the active promotion of these new configurations by opinion leaders and utilities, were significant factors in the rapid proliferation of electric motors.

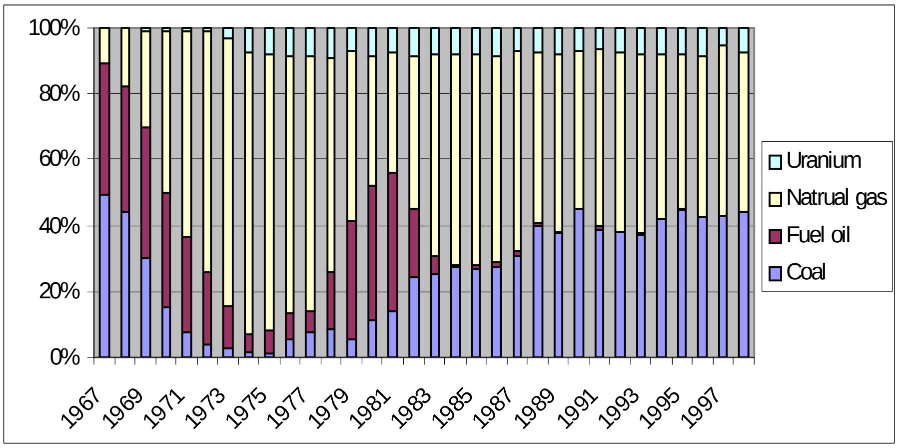
The emergence of the electricity system as a process of institutionalisation

In the early period of the electricity system various technological and organisational forms were available, used, and feasible depending on specific conditions. In a process of institutionalisation where specific actor groups were able to dominate processes of regulatory, normative (who was part of electricity industry), and cognitive (developing a growth dynamics vision and interpretation about how the electricity system was to be organised) institution building, various principles started to underpin the dominancy of the central station electricity system. Continuous optimisation of the system by increasing scales, maintaining reliability and reducing operation costs, and further shaping of demand through increasing use of (new) electrical equipment continued to be important drivers of the development of the electricity system until the 1970s. Electricity systems 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). While the evolution of the electricity system can be traced back as based on a certain logic related to the characteristics of dominant technological and organisational forms, an ascendant path could only emerge through the way these forms became aligned through processes of institution building by influential networks of actors in policy fields as well as in the fields of knowledge, market and civil society.

4.3 The shift from coal to gas in the fossil base of Dutch electricity generation

The Dutch electricity system is predominantly based on the combustion of fossil fuels for the production of electricity. The geographical conditions are ill suited for the production of hydropower and this option is virtually non-existent. Geological conditions provided for coal and gas as a local input for power plants. In the Netherlands thermal power plants dominate the production of electricity. Until around 1965 mainly coal is used as input for power plants. With the discovery of the large Slochteren field, Dutch natural gas becomes available for the production of electricity from the beginning of the sixties and the share of coal drops in electricity generation. Natural gas has become the main fossil fuel in electricity generation as is shown in Figure 4.2, which gives an overview of the fuel base of the Dutch electricity system. Crucial for this changeover to gas was the creation of an institutional framework for the exploitation, development and use of gas and the development of a master plan for a nationwide gas pipeline infrastructure that would connect all private households to the gas grid within ten years (Arentsen and Künneke, 2003; Correljé and Verbong, 2004). Gasunie, a public-private company negotiated between the Dutch state, Exxon and Shell, became the principal actor in the coordination of gas supply and demand. The institutional framework for gas and the associated government resource use policy also directly impacted the power sector's resource base. The initial idea of gas as a transition resource in anticipation of a shift to nuclear energy led to unlimited use of low-priced gas in the power sector. The oil crises changed perceptions, expectations and policy: now prudent use of gas through a small field policy was declared, leading to re-orientation of strategies towards coal. When the effects of the oil crises subsided and the potential of cogeneration for energy saving became apparent, gas re-entered the scene as the preferential resource for power generation.

Figure 4.2 Input shares of primary sources for electricity generation, central producers, 1967 – 1998

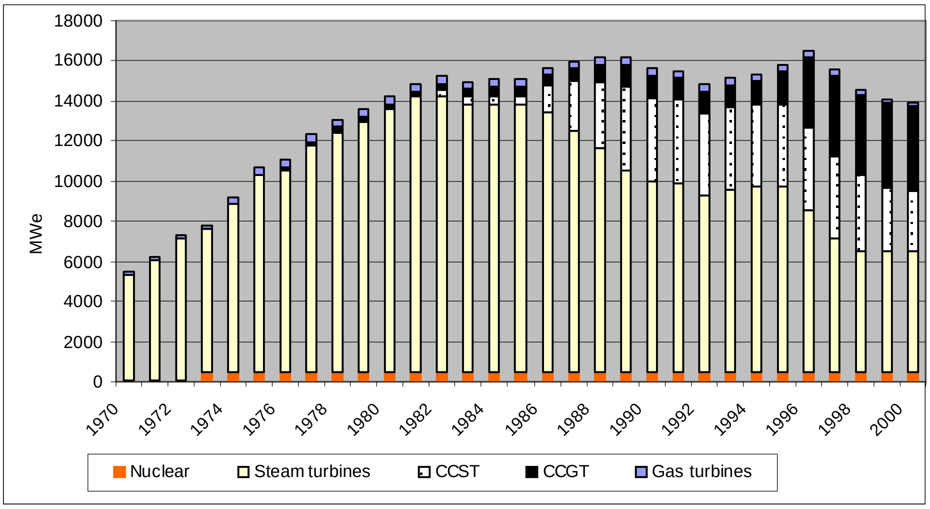


Sources: SEP & VEEN/EnergieNed (1988 – 1999); VDEN (1980).

The technological base of the Dutch electricity system

Figure 4.3 provides an overview of main technology types for electricity generation. Until 1975 electricity generation technology mainly consisted of steam turbine technology. The only serious alternative under consideration until the seventies was nuclear technology. The electricity producers built the first nuclear plant, based on the boiling water reactor technology, in 1968 in Dodewaard. A second plant was built in Borssele in 1973. This plant was based on the pressurised water reactor technology and also owned by the producers. Growth of electricity demand in the period between 1950 and 1975 led to an annual increase of installed capacity of around 500 MW and facilitated the construction of larger units. Technical and economic characteristics of steam turbines in that time are large-scale production, long construction times, long-term investments and high capital intensity (Islas, 1997). The scale of the generation units increased rapidly until the middle of the eighties. Table 4.1 illustrates this increase in scale of generation units throughout the years.

Figure 4.3 Technology types used by central producers, 1970 - 2000[4]



Sources: SEP, 1983, 1986, 1996; SEP, VEEN/EnergieNed, 1989 - 2001; ECN, 1998a; personal communications[5].

Larger scale also led to more efficient fuel use. Through the application of larger turbo generators, higher steam pressures and temperatures, electricity producers were able to improve overall thermal efficiency of the generating plants from 24% in 1953 to 34% in 1968 and 38.5% in 1979 (Verbong, 2000). Other factors responsible for increased efficiency included the use of stronger materials and alloys, and the improvement of the turbines. A thermal efficiency for steam turbines of around 45% was considered to be the maximum for the conventional steam turbine[6] and in the 1990s its technology has matured to an extent that further improvements were unfeasible (Van Hilten, 1996: 91). A scale of around 600 MW was considered the optimum for the conventional steam turbine (Kleinbloesem, 2000).

4 CCST refers to combined cycle steam turbines; CCGT refers to combined cycle gas turbine.

5 In this figure all power plant units in the Netherlands are added. Although this aggregated capacity differs somewhat from figures of the total central installed capacity, the general direction of the developments is correct.

6 The last conventional steam turbines in the Netherlands were installed in the middle of the eighties and have a thermal efficiency of around 41% to 42%. In Denmark recently a conventional power plant has been constructed with an efficiency of 45%. To reach this supercritical pressures and temperatures are used and therefore the materials need to be very strong and overall investment costs are high. Source: interview with representative of the SEP.

Table 4.1 Scale and efficiency of steam turbines

Year	Average Scale	Average Thermal Efficiency	Steam Pressure	Temperature
1946-1955	50- 60 MW	Appr. 25 %	Appr. 86 atm.	Appr. 500 C
1955-1965	120-130 MW	Appr. 30 %	Appr. 180 atm.	Appr. 535 C
1965-1975	200-400 MW	Appr. 35 %	Appr. 180 atm.	Appr. 535 C
1975-1985	500-600 MW	Appr. 40 %	Appr. 190-200 atm.	Appr. 550 C

Sources: VDEN 1980, SEP 1994, and interviews.

In overview, turbine technology, central station electricity, and municipal and provincial monopolies have been the dominant technological and organisational forms in the Dutch electricity system. Regulative, normative and cognitive institution-building were centred around the principles identified by Hughes, which thus also were guiding actors in the Dutch electricity system.

4.4 The nature of institutionalisation of the electricity system in the early seventies

Until the early seventies the growth dynamics paradigm guided decision making and strategic policy as can be illustrated by expectations expressed in 1972 regarding electricity demand and supply for the coming decades. The prognosis in Table 4.2 reflects the belief that electricity demand would continue to double per decade and would be supplied by large-scale central power plants. Nuclear technology was expected to play a crucial role in this expansion due to factors internal to the electricity system such as the relative technological stasis with regard to further improvement of steam turbine technology, and external factors such as increasing awareness regarding the finiteness of fossil sources and the politically sensitive dependency on the Middle East. Around the world the dominant belief was that it would gradually dominate electricity supply in the coming decades. Nuclear technology was expected to substitute fossil base load power plants in the medium future while gas fired power plants could guarantee the flexibility of the production (peak management). Nuclear power plants could provide improvements in the management of the electricity system because they were expected to be highly controllable and would produce relatively cheap electricity (‘too cheap to meter’). The variable costs of nuclear power plants were expected to be small compared to conventional power plants, and it was expected that only nuclear energy could meet the growing demand for electricity (security of supply). Next to nuclear research R&D in that period was focused on the development and improvement of fossil based technologies. In the early seventies electricity supply was not yet ‘bothered’ by pollution, problems of acidification or climate change, or energy saving policies and renewable alternatives. These issues were of no concern to the electricity sector, except for emissions. With regard to emissions of power plants the provincial authorities as shareholders also were lenient with regard to these emissions.

Table 4.2 Prognosis in 1972 regarding electricity supply, in thousands of MWe

Year	Coal	Gas/Oil	Nuclear energy	Total Expected Capacity		Actual Capacity Development
1970	2	7	-	9		9
1980	-	17	2	19		16
1990	-	22	14	36		18
2000	-	35	35	70		21

Sources: TK 1972, White Paper regarding Nuclear Energy, TK Zitting 1971-1972, 11761, p.2; Actual capacity development from EnergieNed (2001).

Technological state of the art

The electricity system consisted of a relative large number, partly vertically integrated, production companies with a regional/local monopoly. Electricity was produced with steam turbine technology. Steam turbine technology was still developing towards larger scale, with main developments coming from foreign companies, while annual production capacity increased with around 500 MW. However, efficiency improvement for steam turbines had almost come to a standstill, leading to what an observer of the US power system called technological stasis: *"the apparent end, in the 1960s and 1970s, of long-running improvements in power generating hardware"* (Hirsh, 1999: 55). The Dutch electricity industry had its own R&D organisation with Kema at the core and various connections to industry. Research and development within the electricity industry had a primary focus on the improvement of the production technology and transmission, and on increasing the reliability of electricity supply. At the production side collaboration takes place through a cooperation of electricity producers (SEP), but a nationally co-ordinated electricity supply was not yet realised. The second high voltage net was in development and in the middle of the seventies more than half of the annual two billion guilders investments by the electricity industry were related to the development of the grid (SEP, 1978: 45).

Institutional setting

The Dutch electricity industry consisted of a varied collection of predominantly regional operating companies, with integrated production and distribution companies and distribution companies, all with municipal or provincial shareholders. Provincial and municipal shareholders to a large extent determined policy of the electricity industry, with a primary focus on social and political goals, the public task of the industry. In electricity production security of supply and reliability were dominant factors. The companies also had an important role in regional employment. The national government held limited influence and control on electricity supply, but had taken initiatives in the early sixties to strengthen its control of the electricity system. This intention was also a consequence of the natural gas discovery in the North of the Netherlands, and the centralised institutional organisation set up for gas supply served as an example for the electricity industry which was foremost locally and regionally organised. Also the intention to develop a national nuclear industry motivated the government initiative to reorganise the Dutch electricity system in order to create the organisational conditions for the application of nuclear technology. The process of reorganisation initiated in the beginning of the sixties would last around 30 years because of discord between government and the electricity industry. Especially the electricity producers have resisted government demands for increased centralisation and co-operation in production because it would reduce their autonomy. Moreover, at the beginning of the seventies, the Netherlands was on the verge of two oil crises that would overshadow reorganisation in the electricity system. Until then economic developments had mainly facilitated further expansion of the electricity sector, and a closed social network of regime actors emerged which were mainly involved in optimisation of large-scale electricity generation and transmission. The oil crises of the seventies put first dents in the stable sociotechnical configuration and in the streamlined parallel developments along dimensions of the regime. It especially challenged the growth paradigm that had been a cornerstone of developments in the electricity regime as the notion of energy saving gained significance. A second important development was the emergence of the gas turbine as a niche that in the course of decades changed the face of the electricity regime.

4.5 The development of nuclear generation technology

High economic growth rates and related steep increases in electricity use led to the search for other options of electricity generation. In the fifties and sixties growing demand was met by the building of conventional steam turbines. In that period the common view was that in the long-term nuclear energy would become the dominant source for electricity generation. In a white paper on nuclear energy of 1957 it was foreseen that from 1975 on all new electricity generation would be met by nuclear power (Lagaaij and Verbong, 1999). It was expected to be a cheap and secure way of electricity generation. Nuclear power did also fit well in the general way of thinking of the electricity sector. It could produce power on a large scale with units up to 500, 1000 or more MWe, it could produce power continuously and reliably for a long period, and thus could easily be incorporated in a system of central production and planning. Although it was costly in terms of construction costs, it was expected to be relatively cheap in terms of fuel costs and costs of operation, and uranium, the fuel source, was abundantly available in various countries. At least until the eighties it was therefore considered as an important future route of electricity generation in the Netherlands by the electricity production sector, although the discovery of large gas reserves in the North of the Netherlands did reduce its necessity.

In 1955 the government established a special national research institute for nuclear energy, Reactor Center Netherlands (RCN[7]). Although all parties involved were supposed to support the institute financially, the electricity generation companies managed to use their contribution for their own nuclear research. They were also able to supplement their nuclear research with funds from the government and Euratom (the European Atomic Energy Community). The technological principles under research by the KEMA[8] differed from the principles under research by RCN. At that time there were therefore two research programs focussing on different nuclear technological principles. Both groups of researchers received funds from the national government and Euratom. The generators paid also their own share, but in fact there were the consumers who were actually funding their research by passing on research cost down to the last level in the value chain. The electricity industry started to gain the necessary knowledge by means of the joint research institute of generators, the KEMA and researched the

7 Later this institute was renamed in Netherlands Energy Research Foundation (ECN) and its mission became much broader.

8 KEMA was initially founded in 1927 as the test institute for the electricity sector (testing electro-technical equipment such as cables, transformers) and later on became the research institute for the sector. KEMA was involved in the development of a Suspension Reactor (SR) from 1951 on.

developments in other countries. Other actors involved in nuclear research were the research organisation FOM (Foundation for Fundamental Research on Matter), the industry, which wanted to obtain a strong position in this new (also economically promising) field and the Ministry of Economic Affairs. According to a White Paper on nuclear energy, government funded R&D for nuclear energy amounted to around 1.3 billion guilders in the period 1955-1971 (TK 1972: 18), roughly around 10% of the total government budget for R&D in that period (Lagaaij and Verbong, 1999). Much of the government efforts were directed towards the built-up of a national nuclear industry.

Until the first oil crisis of 1973, energy R&D was not organised as a separate field, and public spending on energy R&D almost exclusively was focussed on nuclear energy. This took place through funding of fundamental and applied research from various departments, such as the Ministry of Scientific Policy, Industrial Policy and later the Ministry of Economic Affairs and the Ministry of Education and Science. They supplied funding for several research institutes such as FOM[9] and RCN[10] almost exclusively involved in nuclear research and set up after the Second World War to develop Dutch nuclear energy research. From the early fifties on also KEMA, the research institute of the electricity sector, became strongly involved in nuclear research. Research in the Dutch technical universities in the beginning of the 1970s was also dominated by a focus on nuclear research[11]. According to a pioneer in renewable energy, in that period around 20 to 30 professors in nuclear related energy research dominated academic energy research while professors in renewable energy were virtually non-existent (Daey-Ouwens, 2000). Other research areas were gas-fired power stations and gas turbines and improvement of coal-fired steam turbines. All major research institutes in that time either had a dominant focus on nuclear energy or fossil based

[9] FOM, the National Research Organisation for Fundamental Research, was set up in 1946 to co-ordinate nuclear research (Lagaaij and Verbong, 1999: 38).

[10] RCN, the Reactor Center of the Netherlands, was established in 1955 to co-ordinate and concentrate efforts of electricity producers, industry, and science in the nuclear energy field (Lagaaij and Verbong, 1999: 39).

[11] The number of actors initially involved in decision making regarding nuclear energy and nuclear R&D is limited. An analysis of the network with regard to nuclear energy in the seventies showed that only a small number of engineers form the backbone of this network (Uitham et al. in Lintsen (1985). In the network 24 people had three or more functions in a network of 75 companies, electricity supply industries, research institutes, departments, councils related to nuclear energy. One example is an official with a primary function at SEP, and secondary functions at KEMA and GKN, who was also member of the AER and Industrial Council for Nuclear Energy (Lintsen, 1985: 161). According to Uitham et al (1977) the fifteen engineers in this network all originated from the TU Delft, most of them were involved in nuclear energy from the start and had an interest in further extension of nuclear energy (Uitham et al. in Lintsen, 1985: 162).

energy sources. Safeguarding and improving the reliability of the electricity supply through a strong and secure grid also are traditional areas for research and education at the technical universities. Education at the technical universities in the seventies takes place in the tradition of basic principles of fossil-fuelled generation, transmission and distribution along networks varying from low to high voltages (Heydeman, 2000). The traditional power plant and system can be divided in an electrotechnical part and mechanical part, disciplines educated through faculties of electrical engineering and mechanical engineering[12].

Although up to 500 or 1000 MW was considered the minimum scale for a nuclear reactor, the power generators decided to buy a smaller plant than planned to gain experience, reduce costs and to be able to carry out research. This made it possible to get new funding from Euratom. Although the Dutch government intended to built-up a national nuclear industry[13], the Association of Energy Producers (SEP) did not see much in the perspective of the involvement of Dutch industry in the construction of (parts of) the reactor (Lagaaij and Verbong 1999; Verbong 2000). SEP concentrated its nuclear research efforts in its research institute Kema and was not very willing to share its nuclear expertise and did not consider Dutch industry competent enough. Although the industry was invited to co-operate in the building of the plant, Neratoom was not. In the making of the blueprints the industry was hardly invited, so it could not get any experience in doing so. In the construction of the two nuclear reactors foreign companies, General Electric (GE) and Kraftwerk Union, were the main partners. Industry was only involved in providing parts for the first Dodewaard reactor, but the knowhow of GE was only available for SEP and KEMA, much at the displeasure of Dutch government and industry. The plant, based on the boiling water reactor technology, was built in 1968 in Dodewaard. A second nuclear plant was also bought from a foreign company, and built in Borssele in 1973. This plant was based on the pressurised water reactor technology.

[12] Both the TU Eindhoven and Delft historically have strong educational centers with a focus on the electricity system. At the TU Delft and TU Twente research and education on steam turbines, reactors, and thermal engineering are important fields. Foci in education follow those in energy research. Increasing scale of the electricity system also influenced engineers' minds. Installations needed to scale up, and higher efficiencies were required (Boersma, 1998).

[13] This also induced various industrial actors to form a consortium called Neratoom in 1959 for the joint development of expertise for the construction of nuclear reactors. Companies involved were Philips, Stork, Werkspoor, RDM, de Schelde, Machinefabriek Breda, NDSM, Wilton Feijenoord and Comprimo.

The national government was not able to change the course of the events, because of the autonomous position of generators[14]. Due to lack of (legislative) steering instruments, the Dutch government had no real influence on what kind of nuclear technology should be used in nuclear plants. With the experience of the first nuclear power plants government decided in 1974 that the decision-making competence with regard to building new nuclear power plants should be assigned to the Ministry of Economic Affairs.

In the seventies also public concern for safety, the problem of the nuclear waste and nuclear proliferation began to emerge. Public resistance against nuclear energy in the Netherlands became more and more organised and a national energy debate (BMD) was initiated in the beginning of the eighties because of increasing societal concern over future routes of energy supply developed by government in co-operation with the energy supply sector. The BMD made clear that opinions regarding the future energy supply differed widely (SMDE, 1983: 3). Two opposing viewpoints were also most strongly backed by their followers. One viewpoint viewed expansion of nuclear energy supply as indispensable (pro-nuclear viewpoint: held by 17-26% of various groups and individuals participating in the BMD and 13% in a parallel poll[15]). This viewpoint was strongly related with the opinion that regarded unrestricted growth of energy use as desirable. The opposing viewpoint argued for closure of existing nuclear power plants (anti-nuclear viewpoint: held by 33-58%, parallel poll 37%) and was associated with reduction of energy use. The moderate group, however (held by 16-40%, parallel poll 50%), held the opinion that the two nuclear power plants should be maintained, not expanded, and was associated with slowing down of the growth of energy use.

The pro-nuclear viewpoint was most widely held by institutions from the electricity sector. In the scientific field the department of nuclear energy from the association of engineers (KIVI) is strongly in favour of expansion of nuclear energy. The Royal Academy of Sciences (KNAW) expresses the opinion that 'there are no scientific arguments not to make room for nuclear energy'. Arguments for nuclear energy given by the electricity sector are:

– With the current situation and price level for fossil fuels nuclear power is cheapest as electricity source for the base load;

[14] Although provinces and municipalities owned the generators, they acted like private companies.

[15] Discussion in the BMD took place at local level, through sessions with societal organisations, discussions in education, and through institutional participation. A parallel poll was held to poll opinions in Dutch society independent of whether active participation in the BMD took place.

– Application of nuclear energy reduces our dependency and improves stability of prices.

Apart from expanding nuclear energy the general view expressed by the electricity sector is that also coal-fired power plants should be expanded. A minority in the BMD discussion (11-18%) holds this view. The dominant views are that coal use should for the moment be very moderately expanded (36-44%) or that coal should be used as little as possible (39-51%).

There was widespread agreement that research on possible application of renewable energy sources should be intensified[16]. The dominant opinion was that research and application should be started as quickly as possible (56-75%). Another view was that renewable energy sources should be research and applied for in so far as possible (26-38%). Institutions from the electricity sector clearly held this view and argue that renewable energy sources are both technically and economically only potential alternatives in the very long term[17].

In the BMD-process several sessions took place in which followers debated their different viewpoints and tried to convince the opposition to change their opinion. Observations of the steering group regarding these controversy sessions were:[18]

– It was confirmed that societal beliefs, mental worlds 'behind' energy opinions play an important role, which hampers testing of energy opinions;
– Government, the electricity sector, and technical experts sometimes have great difficulty to emphatise with views, opinions, prejudices en societal beliefs that are put forward by society. They (the experts) are not always able to recognise that also their own standpoints are motivated by emotions based on norms and values.

Summarising the national energy debate clearly illustrates the belief of the electricity sector that large-scale application of both nuclear energy and coal is a logical and desired route for future energy supply. It also illustrates the limited capacity of the sector, and especially of technical experts, and the majority of engineers, to disengage itself from the past achievements of the electricity system, its artefacts and the technologies that built the system.

Despite societal resistance, but in line with the resource diversification orientation in national energy policies, the Dutch government approved

[16] Stuurgroep Maatschappelijke Discussie Energiebeleid, Eindrapport BMD, pp. 165-175, 1983.
[17] Ibid. and appendix A1.
[18] Stuurgroep Maatschappelijke Discussie Energiebeleid, Eindrapport BMD, pp. 38-39, 1983.

further investments in nuclear power plants in the 1980s. Government and the power generation industry considered nuclear as a necessary fuel source for future power generation. The Dutch government was at the point of authorisation of the building of two or three new nuclear plants, when the Chernobyl accident occurred and this led to a decision to postpone the authorisation, although it was suggested that there was no connection with the accident. The general tide was also starting to turn against nuclear energy. The consumption of publicly generated electricity was not rising due to the oil crises and through energy saving measures. Moreover, due to lower oil prices the costs of nuclear power were no longer competitive with the costs of fossil-based electricity. There was enough supply of natural gas and it was possible to import electricity at lower prices. After 1987 nuclear power has no longer been a serious option for power generation, and Dutch parliament decided to phase out nuclear, by planning to close down the only Dutch nuclear plant still in operation. The knowledge infrastructure for nuclear energy did not disappear completely, initially domestic support was legitimised based upon maintaining up-to-date knowledge and expertise in the case major problems were solved (e.g. nuclear waste, and inherently safe reactor designs), later new markets were developed in the nuclear activities of ECN.

Literature on the development of nuclear energy in the Netherlands is extensive and we summarise here some of the main conclusions[19]:

- Dutch government implemented an active R&D strategy for nuclear energy, and pursued the development of a national industry;
- The electricity sector was interested in the implementation of nuclear energy as a proven, mature technology, and was much less interested in the development of a national industry;
- Nuclear energy fitted the know-how and routines of the electricity sector regarding large-scale, long-term investments, and the guiding principle of large central production units producing continuously for base-load electricity;
- The decision making process regarding nuclear energy proceeded with very limited actors involved (government and sector); was from the onset very technocratic, and did not involve societal groups;
- The development and possible application of nuclear energy was something fundamentally new to both Dutch society and the knowledge infrastructure. Competencies regarding the technology had to be built up (and were built up both in terms of organisation, R&D and education); however competencies regarding the ‘sociotechnical’ issue of risk were absent;

[19] This is largely based on Hofman and Marquart (2001).

– The government and the electricity sector, in ‘tacit’ co-operation had a strong belief in nuclear energy, but both actor groups could not understand that society at large did not share that belief. More importantly they did not acknowledge that these beliefs were based on certain mental models, in their case framing the risk issue in rational models of calculation.

Several moments are crucial in the story of nuclear energy:
– Although government efforts were focussed on developing a national industry the electricity sector decides to buy foreign technology, this accelerated the political discussion regarding the grip of the national government on the electricity sector;
– Due to increasing societal resistance the government was more or less forced to initiate a broad societal discussion. Although the outcomes made clear that there was no basis for further nuclear power plants, Dutch government still felt that nuclear energy was inevitable;
– The disaster at Chernobyl is more or less decisive in ending the future of nuclear energy in the Netherlands.

Some overall observations can be made:
– The government R&D strategy was largely top-down oriented, and did structure some of the R&D efforts through RCN and Neratoom, but government policy was not able to align various actors in a shared course for nuclear energy research and development;
– The government expectations regarding nuclear energy were far too optimistic, first of all regarding the potential for building a national industry, secondly the belief that competencies could be built up, and thirdly the idea that government could decide what the market needed; the Dutch government in that period sees technology as controllable and malleable;
– A technocratic process not well embedded in society, with some fundamental new features (here the issue of risk), is in this case not endorsed by society;
– Society in the fifties was fundamentally different from society in the seventies: environmental concerns were spreading, and societal groups were voicing their beliefs. These changes were not translated into the decision-making processes on nuclear energy;
– Despite a changing perspective towards energy saving and renewable energy dominant actors within the electricity system still had high expectations of nuclear energy until after Chernobyl;
– In the fifties through eighties an influential social network was formed around nuclear energy, and was rather dominant in various councils related to electricity. Verbong (2005: 174) argues that this network was still influential throughout the nineties and is part of the explanation for

ongoing significant national funding for nuclear energy until the mid-nineties.

The case of nuclear energy makes clear although this path was strongly embedded in processes of institutionalisation within the electricity system, it especially represented a different interpretation of the electricity system within society for a variety of actor groups. The successful inclusion of a new element within the electricity system demanded alignment with broader knowledge, policy, economic and societal institutional arrangements. While within the knowledge, policy and market dimension this alignment took place by interpreting the suitability of nuclear technology within the growth dynamics paradigm and within the central station electricity system, various actors from civil society (including several scientists, policy makers, and business representatives) interpreted inclusion of nuclear technology in a totally different way. Mobilisation of this opposition and reinforcement of their position due to several incidents with nuclear installations blocked further development of the nuclear path. Crucial was also that mobilisation took place around an alternative path based on energy saving and cogeneration, and that this alternative 'institutional logics' was developed in a good fit with increasing environmental concerns, energy price concerns, and with interests of a range of energy-intensive industries. Nevertheless, the nexus created between knowledge, government and the electricity sector through the establishment of RCN, later ECN, and later the nuclear research group (NRG), in which the nuclear activities of ECN and KEMA were merged within ECN, has maintained a strong position. Both funding sources and the strategic orientation of research have changed fundamentally, with markets, such as the medical sector, and international funding sources, becoming dominant relative to national funding, and with a shift to medical nuclear research. Over the years the share of nuclear research in ECN has remained stable around a level of 40% (Verbong, 2005: 43). Also expectations regarding the future potential of nuclear energy remain as was shown in four recent scenarios developed at ECN (Bruggink, 2005), where in one scenario the high temperature reactor (HTR) was applied as a decentral means of cogeneration on the island of Texel, a concept developed at ECN and NRG (Verbong, 2005).

4.6 Hybridisation of steam and gas turbines

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 as 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 systems change 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 at the end of the sixties;
- Knowledge regarding gas turbine technology had several similar features to steam turbine technology and alliances between companies involved in 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".*

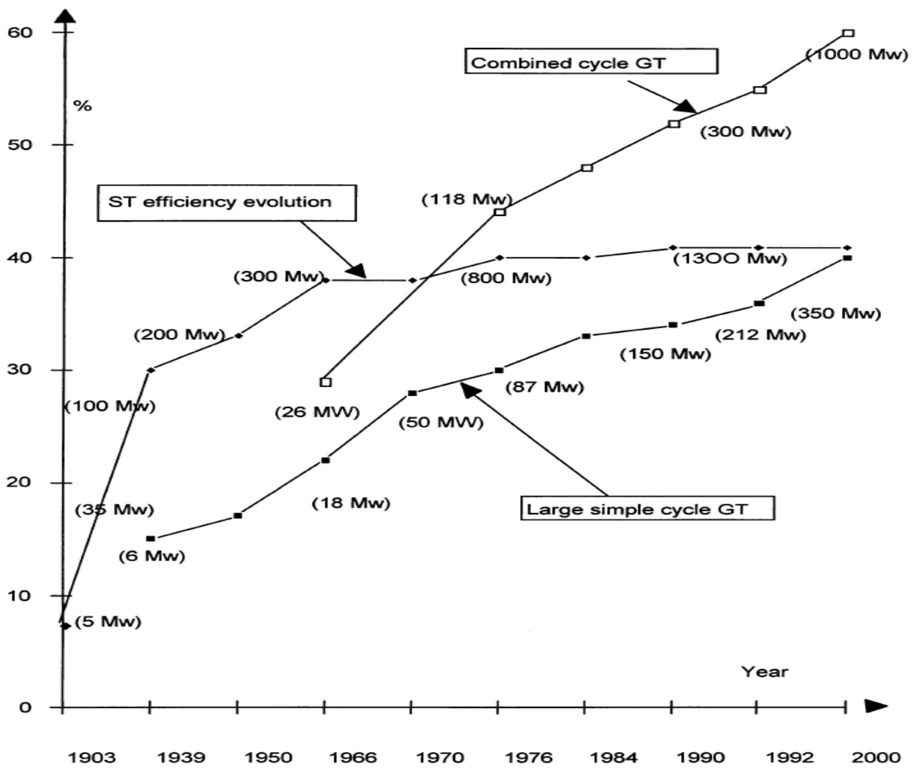
Electricity companies increasingly acknowledged the importance of combined cycles. Manufacturing companies, such as General Electric, Westinghouse, Kraftwerk Union, and Brown Boveri all implemented development and marketing programmes for combined cycles. Between 1960 and 1974, 17 combined cycles came into operation with electricity companies in Europe and in the middle of the seventies *"combined cycle gas turbines displayed techno-economic characteristics which were 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 fist 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 (CCST in Figure 4.2) 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 combined cycle gas turbine (CCGT) configuration that could only operate on natural gas came in operation. Figure 4.4 illustrates the evolution of efficiencies for steam turbines, gas turbines, and combined cycle gas turbines. Availability of natural gas facilitated the application and diffusion of gas turbine technology in the Netherlands but the penetration of combined cycles 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 was 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.

Main conclusions regarding the introduction of hybrid forms of gas and steam turbine technology are:

– The development of hybrid forms of gas and steam turbine technology took place in foreign countries, with crucial links between military induced jet engine R&D and industrial R&D on gas turbines;
– The introduction of gas turbines and combined cycles came at a time of technological stasis in the electricity sector: "*the apparent end, in the 1960s and 1970s, of long-running improvements of power-generating*

hardware" (Hirsh, 1999: 55). Application of gas turbines and hybridisation with steam turbines ended this stasis;
- The Dutch electricity chose to apply combined cycles when the technology had proven itself in other countries;
- Availability of natural gas and the gas infrastructure facilitated the introduction and diffusion of gas turbine technology;
- Although not involved in the development of combined cycles, the Dutch knowledge infrastructure (Kema, electricity sector, various turbine producers such as Stork and Thomassen-Werkspoor, the Gasunie) had sufficient competencies to successfully apply the new technology;
- Government played virtually no direct role in the introduction and diffusion of gas turbine technology but indirectly played a role due to the changeover in energy policy towards energy saving and efficiency improvement.

Figure 4.4 Efficiency evolution of steam turbines (ST), gas turbines (GT), and combined cycles gas turbines (Islas, 1999: 139).



4.7 Distant heating as a form of cogeneration

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 introduced after the oil crisis, including the stimulation of 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[20], but was pressured by government to develop this new technological path. A committee was set-up in 1975 to investigate the potential of district heating. Although the SEP was initially sceptical regarding the economics of district heating, in light of energy saving targets, government pressure, and growing insights regarding the potential, from 1977 on 16 large scale district heating projects were initiated. The focus on larger scale was expected to improve the cost picture. Initially, the district heating projects were not very successful due to several factors (Novem, 1994; Arentsen et al, 2000):

- The lack of a infrastructure for heat distribution made the projects very costly;
- Early calculations were too optimistic regarding the heat demand, also because energy saving measures (such as isolation of houses) led to lower heat demand;
- Power plants were not designed to produce heat, and needed to be redesigned both in terms of technology and location;
- Technical and economic knowledge of distant heating systems was lacking and the projects were hit by several technical and economic problems;
- Distant heating had to compete with local heating on gas based on the extensive gas infrastructure in the Netherlands, this included competition with gas companies;
- Distant heating suffered from negative consumer image.

In the course of decades, however, accumulated experiences with district heating led to better fine-tuning of power plants with local heat demand, while also combined cycles (and their more flexible scales) were better suited for district heating.

[20] In central cogeneration 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 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 increasing 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.

4.8 The development of coal technology

The second oil crisis intensified the strategies for energy saving and resource diversification. Increasing urgency of the energy crisis cumulated in two significant developments in this period. Nuclear energy became unfeasible due to societal concern amplified by the Chernobyl crisis. Now, coal was seen as the only alternative to oil and gas in the medium term. It was deemed possible that in the coming 20 to 30 years coal would become the single source for electricity generation (TK, 1979: 139). Secondly, environmental concerns, apart from the finiteness of energy resources, played only a limited role in technological development for electricity generation at the beginning of the eighties. With the closure of nuclear energy as a technological path for electricity generation, expansion of coal emerged as the favoured alternative to gas-fired power plants. Several conventional power plants were reconfigured to the use of coal, and plans for the construction of new coal-fired plants were approved. Moreover, in order to reduce environmental impacts of coal[21], a coal research plan is set up to develop new coal

[21] Environmental concerns regarding the emissions from coal combustion increased during the eighties. While in the course of the sixties policies were formulated to control air pollution in the Netherlands, and especially the formation of smog. Whereas the Air Pollution Act was concluded in 1970, specific emission standards for fossil fired plants, first for SO_2 and later for NO_x, were only introduced at the beginning of the eighties (Dinkelman, 1995). From the 80s on the effects of acidification became an important environmental constraint for the electricity sector also in the light of the shift towards coal. Effects of acid rain became visible through the deteriorated state of forests and lakes, especially in Nordic countries where the assimilative capacity of the soil for acid substances is relatively low. More importantly, in this period also the scientific community moved to consensus on labelling the emissions of SO_2, NH_3 and NO_x and transboundary transport of these emissions as major factors for acid rain and public attention for the harmful environmental effects of these emissions rose (Dinkelman, 1995).

technologies, especially gasification of coal, and techniques to reduce the negative environmental impacts coal-fired power plants, such as desulphurization. Research efforts on coal became second in size next to nuclear research. Coal gasification technology[22] was developed by several oil companies[23], such as Shell, Texaco and British gas, as a future alternative to oil as a source for its products and some test plants were operating in the USA and Germany. Because of the environmental problems associated with conventional coal-fired power plants the electricity sector started to explore the potential of gasification. Coal gasification in combination with steam and gas turbines (KV/STEG) was expected to give similar emissions of NO_x and SO_2. After two years of exploration of the technological options, SEP decided, on technical grounds, to use the technology developed by Shell (Zon, 2000). Coal gasification was implemented in the nineties at a 250 MWe demonstration plant in Buggenum, total costs of 850 million guilders were financed by the SEP. In the demonstration phase some major problems occurred, mainly in the conventional part of the plant: the gas turbine. Characteristics of the synthesis gas called for adaptations in the gas turbine. The producer of the gas turbine, Siemens, invested tens of million guilders to improve its operation. The Buggenum plant became operational in the middle of the nineties as the first and largest coal gasification plant for electricity generation in the world at that time was considered technologically unique (Böttcher, 1999). After a demonstration period until the end of 1997 the power plant became part of electricity production by the SEP. In the transition period to a liberalised market, it became clear that the plant was not competitive due to the high investment costs[24]. With the dismantling of the SEP the plant became labelled among the stranded costs, burdens that were to be distributed among power producers and

[22] Gasification is the process of reacting a heated carbon source – whether biomass, coal, or even low qualitiy grades like lignite, with oxygen and steam to produce syngas. Syngas – a mixture of carbon monoxide and hydrogen – can also be produced from a range of other feedstocks including tar sand, oil and natural gas. Syngas is used for electricity generation as well as to make base chemicals for the petrochemicals industry (Source: website of Shell, http://www.shell.com/royal-en/content/0,5028,25544-51272,00.html).

[23] For example, Shell had invested several hundreds of millions US $ in the technique at its laboratory in Amsterdam (KSLA), and in a test facility in Hamburg. Texaco had a facility in operation in Coolwater, USA, for the production of hydrogen, with use of around 100 tonnes of coal per day. As gas prices were expected to rise in future years because of its more acute finiteness as compared to oil and coal, oil companies saw opportunities to sell the synthesis gas produced by gasificiation. This gas could in the long term also replace oil as the basis for most of their products (Roggen, 2000; Zon, 2000).

[24] According to the former director of Demkolec, KV/STEG could be competitive to conventional coal-fired power plants with a capacity above 600 MW. A plant of that size would require an investment of around 1250,- Euro per kW capacity (Zon, 2000).

government[25]. Nevertheless, many in the electricity world still see coal gasification as a major future technological option with a large potential market in countries that depend largely on coal as an energy source, for example Shell has already licensed the technology to China[26] (Böttcher, 1999; Zon, 2000). An additional characteristic of gasification is that in the production of synthesis gas it is relatively easy to isolate CO_2. In a new application of gasification of oil residual at a plant of Shell in Pernis, CO_2 is extracted and distributed to horticulture companies[27] while the syngas is used for petrochemical purposes.

Overall conclusions regarding the re-emergence of coal are:

- With the closure of the nuclear energy route, coal became the most logical alternative to gas in the perspective of the electricity sector and government;
- Coal clean-up technology and clean coal technology has been strongly stimulated by government funding and by the electricity sector;
- Increasing environmental concerns and the second environmental wave (NEPP in 1989) steadily deteriorated the government attitude towards coal, the climate problem accelerated this due to the high CO2 contents of coal;
- Coal gasification, technologically developed by oil companies, was seen by the electricity sector as a promising alternative because it could provide a cheap long-term source, has a relative good environmental profile and can approach efficiencies of the most efficient power plants;
- The technological success of the Buggenum plant was also due to the strategic interests seen by a leading gas turbine producer that participated in the project;
- The electricity sector, through its collective organisation SEP, was able to finance the construction of the Buggenum plant by transferring high investment costs to consumers, the breakdown of SEP due to ongoing privatisation has made the plant unprofitable due to high capital costs;
- Experience with coal gasification has also led to further application of the technique, for example for oil residue (which is commercially applied), and further R&D on potential application with biomass;
- While the Buggenum plant was seen as one of the most advanced examples of energy technology; it became economically labelled under

[25] SEP was dissolved due to liberalisation and privatisation and the Buggenum plant has been sold to NUON who uses it as a biomass gasification plant.

[26] According to Böttcher (1999: 22) also in Japan coal gasification is seen as an important medium term option in which various gaseous products can be transported (for example through co-operation with China) to be used both for energy supply and as input for chemical processes.

[27] CO_2 levering aan kassen bijna rond, in Nieuwsblad Stromen, August 18, 2000.

stranded costs in the course of liberalisation, this also signified the change of electricity production from mainly technologically and supply-driven to economically driven;
- At the global level, coal will remain one of the dominant fuel sources for electricity generation, also because of its long-term availability in for example a fast industrialising country like China, while also conditions may be more supportive for gasification technology, as seems to be the case for China where in 2004 more than ten gasification technology licenses have been bought.

The case shows how strong the focus of energy R&D within the electricity sector was on extending specific technological and organisational forms within existing institutional frameworks. Moreover in the institutional setting of a SEP collective of monopolistic producers, R&D and investment costs could be transferred to consumers enabling huge investments such as for the Buggenum plant. In a liberalised, competitive market, these types of investments are unlikely to occur, unless expectations of projects are rather robust in terms of expected turnover, costs, reliability, and efficiency, and/or government plays a central role.

4.9 Combined heat and power generation[28]

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 cogeneration 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% in 1997 (Arentsen et al., 2000). Several factors explain the fast expansion of decentral cogeneration:
- Gasturbine technology had become efficient and available for medium size cogeneration capacities[29];
- Legal opportunities to produce decentral cogeneration 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;

[28] In chapter five a more detailed analysis of decentral cogeneration is carried out.
[29] In the small capacity range the use of gas engines was common.

- Both economic incentives (investment subsidies and beneficial gas tariffs for CHP-appliances) and adaptations (in various steps) in remuneration tariffs encouraged decentral cogeneration;
- The obligation for distributors to purchase surplus electricity delivered to the grid by decentral cogeneration 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, cogeneration was a major instrument to reach targets agreed in the covenants;
- The development of a policy package to stimulate cogeneration (investments subsidies, fiscal measures, attractive gas tariffs and remuneration tariffs) in combination with the set up of a specific cogeneration-office (PW/K) 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 cogeneration 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 (VKW). 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[30] 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[31] and increasingly were

[30] L. Vos in 1951 (Binnen paal en perk, overdruk uit Electrotechniek van 20-12-1951) quoted by Buiter and Hesselmans (1999: 96), translated from Dutch.

[31] For example, in 1957 VKW became member of FIPACE, the international organisation of industrial electricity producers. FIPACE was established in 1954 by West European

recognised as a significant industrial interest group[32]. The emergence of natural gas and the development of gas turbine technology increased opportunities for industrial cogeneration. 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[33], 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 cogeneration 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 cogeneration 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 cogeneration Moreover, the electricity act facilitated new actor constellations, especially coalitions between industry and distributing companies, thus enabling effective application of decentral cogeneration.

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 they had to meet, something for which decentral cogeneration was much better suited (Patterson, 1999). The

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industries because of commercial barriers enacted by monopolistic suppliers of electricity (Buiter and Hesselmans, 1999).

32 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.

33 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).

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.

4.10 Wind energy development in the Netherlands

Before the oil crisis the electricity sector and the government were clearly focused on nuclear energy and gas turbine technology. In the light of low oil prices and the promise of nuclear energy, also development of other principles was not considered viable. Earlier, in the fifties when coal shortage was expected, experiences with electricity generation through wind had been carried out by the Foundation for the Generation of Electricity by Windmills leading to the conclusion that the traditional Dutch windmills were not suited for electricity generation. The foundation was dissolved in 1972 (Verbong, 1999). Some actors were focussed on small-scale applications of renewable sources, in the light of growing concern over the finiteness of resources (especially after the Club of Rome publication in 1972) and early signs of the oil crisis. Early pioneers in solar energy, wind energy and biomass technology were dominantly focussed on applications in developing countries where an electricity grid was either non-existent or less developed. The oil crisis and the first White Paper on Energy marked the start of a strategic policy for alternative options for electricity generation. Based on recommendation from the newly set up LSEO (National Steering committee for Energy Research), technology programs for wind and solar energy (mainly thermal) were initiated to explore the potential technological options. According to Verbong (1999:142) for wind energy:

> *"the LSEO recommended the evaluation and development of several different types of wind turbines and the construction of prototypes. A remarkable aspect of this recommendation is the criterion that was used to distinguish between small-scale and large-scale production units. In the LSEO's view, even a small-scale unit consisted of at least 20 to 30 turbines. This clearly reflected the dominant reference frame of the large-scale electricity-generating companies".*

Early efforts in wind energy development

In the first program (NOW-1) eight Dutch companies and institutes were involved in research under project management of RCN, later an independent project management office, BEOP, was founded. Two basic principles were under research, the Horizontal Axis Turbine (HAT) and the Vertical Axis Turbine (VAT). Fokker, ECN and an engineering company were involved in VAT research. Principal partners in HAT research were the National Aerospace Laboratory (NLR), TU Delft, ECN and Stork.

A Dutch wind industry emerged in this period. One of the pioneers in the construction of wind turbines, Henk Lagerwey, started his own company and was affiliated to the TU Eindhoven. More companies emerged during the seventies (Polenco in 1976/7, later renamed Nedwind, Windmaster in 1978) and in the beginning of the eighties. NOW stimulated the development of various prototypes and nine companies were supported actively (Verbong, 1999).

Small-scale application of wind energy was mainly driven by possible transfer to developing countries. A wind energy group at the TU Eindhoven was involved in projects as early as 1974, and in collaboration with TNO and RUG, later followed by DHV, UT and LUW (Smulders, 2000) developed consultancy projects and training on wind energy in developing countries, funded by development aid.

In overview, early efforts in wind energy were shaped by:

- The existence of two coalitions for wind energy: one based on 'institutional logics' from the electricity regime and involved in R&D to integrated large scale wind turbines in centralised electricity generation; another coalition, more grassroots oriented, and focussed on small scale development and implementation of wind energy both in the Dutch and developing countries' setting. These coalitions thus initiated from contrasting perceptions regarding the nature of the problem and solutions, different frames of reference as the grassroots coalition developed from a local needs orientation and the energy coalition from a central station model orientation (see also Grin and Van de Graaf, 1996, for a similar interpretation of the Danish wind case);
- The initial belief within the electricity sector that development of large scale wind turbines was the only feasible route for wind energy application in electricity generation;
- A focus on the technical aspects of wind energy, amplified by government funding of development of prototypes;
- Virtual absence of market driven forces and 'local' aspects such as location, planning and permitting.

Further experimentation with wind energy

In the eighties, the international momentum for wind energy was high. In various countries government support was strong while the wind turbine industry could deliver reliable wind turbines in the area of 50 to 100 kW. Wind turbine production and application especially boomed in California and Denmark helped by a mix of incentives for producers and users and political support. In comparison, Dutch wind energy developed more slowly. In 1985 9 MW wind capacity was installed in the Netherlands compared to 911 MW in California and 60 MW in Denmark[34]. Based on several sources[35] the following explanatory factors can be identified:

- The focus was on large scale development, without establishing trajectories of learning through the development of small scale wind turbines (see also box Sexbierum wind farm);
- The complexity of wind turbine technology was underestimated, leading to the installation of wind turbines that were insufficiently tested. In comparison in Denmark a test station for small wind turbines was set up in 1978 while the early pioneer Johannes Juul had started small-scale wind turbine development in the 1950s and his experiences were utilised in the 1970s (Jorgenson and Karnoe, 1995);
- While the grassroots coalition largely lost out in expanding an alternative to the institutional logics of the electricity sector coalition in the Netherlands; in comparison in Denmark the bottom-up strategy of the grass-roots coalition was successful from the mid 1970s to mid 1980s in building local decentralised energy systems with strong local involvement (among others through cooperatives at least 160.000 households owned shares in at least one turbine in the mid 1990s according to Jorgensen and Karnoe, 1995: 75). Further developments in Denmark were a slow up scaling of the turbines, a shift from domestic to foreign markets, and the formation of managerial approaches to marketing and exporting of wind turbines. Grin and van de Graaf (1996: 87) illustrate how change in management paradigms co-evolved with the changes in the nature of firms in the wind sector in Denmark. In this process the role of utilities and a more large-scale centralised approach starts to gain the upper hand which also explains the recent focus on off-shore wind-farms in Denmark;
- The electricity sector was handed a key role in the development of large-scale application of wind energy and its connection to the grid, however

[34] This is illustrated by the market share of Dutch wind turbines in the main market at the beginning of the nineties, California. Of the 15,856 wind turbines 63 were from Dutch origin (0%) as compared to 6,778 (43%) from Denmark, 660 (4%) from Japan, 283 (2%) from Germany, and 174 (1%) from Belgium (Gipe 1995: 36). The only Dutch company with significant export was Lagerwey, with wind turbines in the 75-80 kW area (Verbong, 1999: 153).

[35] Gipe, 1995; Wolsink, 1996; Verbong, 1999; Smulders, 2000; de Keijzer, 2000; Beurskens, 2000.

it lacked experience and commitment, and was not part of R&D networks involved in wind energy development;

- Although ambitious policy goals were set (in 1985 a 1000 MW target for 2000), and R&D was supported, measures were mainly of a top-down nature, and not accompanied by implementation strategies and market incentives (subsidies were based on installation of capacity and not on yield, thus giving no incentive for performance);
- Pay back tariffs for electricity delivered to the grid were low relative to other countries (in 1994 55% of consumer electricity prices compared to 85% in Germany, 142% in Denmark and 189% in the UK) (Wolsink, 1996);
- Efforts were concentrated at developing technology and industry and not on developing local involvement, networks and institutional frameworks for the developing appropriate sites and implementing wind power at the local level.

The development of a wind farm in Sexbierum

After the first wind program had resulted in the development of several prototypes of wind turbines the second wind program was focussed on first application in electricity generation. The focus was on large scale application of wind energy, and in the beginning of the eighties it was decided to develop a demonstration wind farm of 18 wind turbines with a total capacity of 5.4 MW. The experiences of this wind farm would serve as a basis for recommendations regarding the integration of wind capacity in the electricity system (SEP, 1983: 7). The importance of the exploration and design of the wind farm was particularly stressed by the Ministry of Economic Affairs, and the Ministry decided to give SEP the leading role[36] (Verbong, 1999: 150). At that time this was the largest application of wind turbines in the Netherlands. SEP was involved under the condition that government would finance half of the construction costs. Although SEP expected that wind turbines would not give large technical problems, operation of the wind farm led to unforeseen problems. The strong vibrations and the nature of wind as an unstable source hampered scaling up of the wind turbines (De Keijzer, 2000). Variability of wind and the fact that wind turbines are switched off above certain wind velocity led to variable power supply with extra demands on the control of thermal power capacity (SEP, 1983: 14). Also the wind turbines chosen were prototypes of newly designed turbine types and hardly tested, leading to technological problems and poor performance (Verbong, 1999: 154). In 1986 construction of the wind park started, the park became operational in 1988. Initially, it was expected that wind power could replace around 20% of the conventional base load capacity, based on the experiences this was revised downwards to 16.5%. The negative experiences ended SEP's involvement in wind energy.

[36] According to Verbong (1999: 150) the reason for this transfer was unclear. "*SEP (…) had little experience with wind turbines and was certainly not in the wind advocates' camp, to put it mildly. In fact, SEP (…) was at that time the main nuclear energy supporter. Moreover, because of the autonomous position of the electricity sector's institutions and subsequent 'monopolistic' behaviour, relations between the sector and other research institutions and with industry were at times strained*".

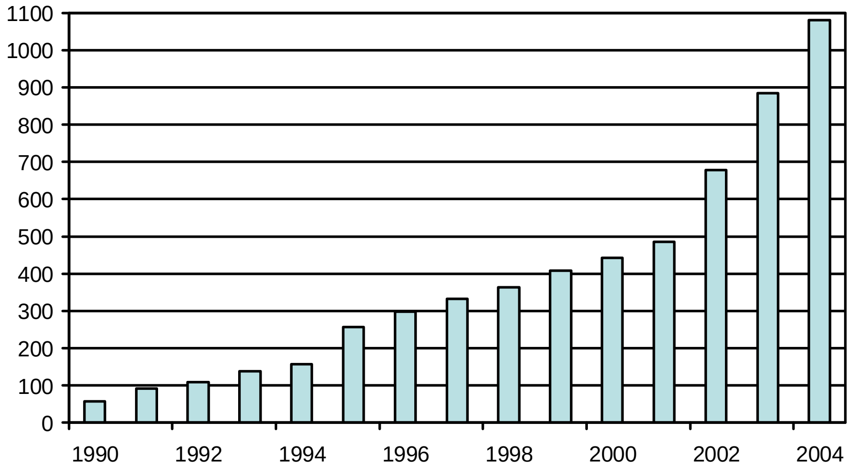
More robust plans for wind energy

Rising attention to the climate change problem in the nineties increased momentum for wind energy. Both wind energy production and capacity has grown rapidly in the 1990s. Electricity distributors have played an important role in this development, fostered by an environmental action plan (MAP) set up as a part of an environmental agreement in 1991 with government to reduce CO_2 emissions by the distributors. The MAP came as a reaction on the task set in the NEPP and Energy Saving Act of 1990 for the electricity sector. Part of the MAP was a 250 MW Windplan, set up by eight distributors. The implementation of the plan however experienced difficulties, such as spatial integration of the wind turbines. According to Wolsink (1996: 1084) the distributors lacked experience with small-scale physical planning and local politics. Although the ambitious goals of the windplan were not reached, wind capacity steadily increased. According to van Zuylen et al. (1999: 22) this can be explained by the cumulative effect of the measures available at the time, which illustrates the sensitivity of wind energy implementation to the subsidies; subsidy, green funds and standard remuneration for electricity generated from wind. In 1996 all wind subsidies were abolished and replaced by fiscal measures. Anticipation of this shift from subsidies to fiscal measure led to a peak of implementation in wind energy capacity in 1995 (with 100 MW installed that year by mainly energy distributors and small private investors) what was twice as high as in the years that were to come. Apparently, entrepreneurs were able to introduce a higher level of urgency within lengthy permitting procedures with regard to time deadlines set and this led to a peak of projects being forced through (Agterbosch et al., 2004). The shortage of locations for wind energy has long been considered to be the main problem hampering wind energy development and introduction (EZ, 1999). The wind turbines are considered (especially by local actors) to have a negative visual impact on the landscape, a negative impact on birds and to produce noise and by this do not meet the expectations (or goals) of actors involved. However, recent studies in a number of municipalities indicate that the attitude of the majority of citizens towards wind energy in general is positive. Environmental groups also pointed out feasible locations for wind energy, taking into account impacts on landscape and nature. In their plan, published in 2000, it is concluded that ample locations for wind energy exist where public resistance is likely to be low and with the scope to quadruple wind capacity (SNM, 2000). Also Wolsink (2000) argues that public acceptance is not the main problem for wind energy development, but that slow development mostly related to structure and dominance of the utility sector, ineffective planning of wind sites, and the top-down orientation in energy policy with lack of local participation and commitment in goal-setting, policy formulation and implementation. The fact that wind power capacity has grown steeply in Germany, with similar levels of public acceptance as in the Netherlands (Wolsink, 2000), indicates that this is not the major problem. Factors playing a role in Germany are a much more effective planning system, with potential wind locations earmarked in zoning schemes which enables shorter procedures, and stable incentives through the electricity feed law and its feed-in tariffs for wind power.

Liberalisation fosters implementation of wind energy by other actors

Actors involved in implementation of wind energy were energy distributors, private project developers, agriculturists and co-operatives. Initially, the distributors were the most important through the years in terms of ownership, but new independent power producers became more prominent after the phasing of liberalisation was formalised through the electricity act of 1998, and renewable based electricity was exempted from the regulatory energy tax. Although not all plans of the distributors turned out so well, at the end of the nineties about 50% of installed capacity was owned by the utilities (WSH, 2000). Two factors were mainly responsible: the environmental action plans of the distribution sector and the emergence of green electricity as a separate product and market. Opening up of the electricity market due to liberalisation also reduced entry problems of other actors, for example through the development of beneficial rules for connection to and use of the grid. Until liberalisation distributors had been able to shape the conditions under which local producers could enter the grid, often resulting in relatively high costs for those producers. Especially small private investors, independent power producers and cooperatives were able to expand their installed capacity after the liberalisation of the green electricity market in 2001 (Agterbosch et al., 2004). Table 4.4 shows the evolution of wind capacity in the Netherlands and the acceleration that took place after 2001. Implementation of wind energy did not realize the target of 1000 MW in 2000 that were announced in 1985. The main barrier for further uptake of wind energy was the shortage of wind locations, often due to the difficulty of obtaining sites through legal procedures and overcoming objections. Also while ambitious targets were set by the national government, lower governmental bodies were much less committed to implementation. Several further initiatives were taken to escape the deadlock with regard to siting, especially since the liberalisation of the green electricity in 2001 led to a shortage of domestic locations for renewable energy. They included preparations for offshore sites for wind farms and establishing administrative agreements with provinces and municipalities for uptake of wind energy.

Table 4.4 Evolution of installed capacity of wind in the Netherlands (in MW)[37]



In 2001, an administrative agreement, called Blow, was reached between five ministries of the national government, the twelve Dutch provinces and the association of Dutch local authorities to intensify and fine-tune wind energy development. The agreement set an objective of 1500 MW wind capacity installed on land in 2010. Specific wind capacity targets were set for each province, but individual municipalities were not committed to the agreement. Blow has intensified interaction between, and increased commitment of, various governmental bodies and layers regarding wind energy, and facilitated standardisation of approaches for solving recurring bottlenecks, such as noise-effects, shades, and integration in landscapes (LSOW, 2003; 2005). Especially provinces have started to take leading role as information providers, planners, and stimulators. Financial support for provinces, among others to integrated wind into provincial spatial plans (POPs), and for the association of municipalities to support wind turbine implementation through the development of manuals for municipalities, also improved the climate for wind energy. Moreover, in 2002 a national climate covenant was agreed between national government, provinces and municipalities, under which provinces and municipalities were eligible for subsidies for implementation of activities to reduce emissions of greenhouse gases.

[37] Data based on CBS (2004) except for 2004 data from the Wind Service Holland website, accessed on 4 July 2005 at http://home.planet.nl/~windsh/statistiek.html.

Recent years (2002 to 2004) show rather high and stable increases of wind power capacity with around 200 MW and in 2005 total installed wind power capacity reached 1150 MW[38]. Private investors (farmers, independent power producers, cooperatives) take the dominant share of investments with utilities responsible for around a quarter of investments in 2003 and 2004[39]. Liberalisation of the green electricity market and increasing demand for green electricity, exemptions for the regulatory energy tax, and increasing attention for wind energy at different government layers played a role in creating a more positive climate for wind energy. Global experiences, continuous expansion of the knowledge base, and further upscaling and improvement of technological concepts have contributed to strong expectations regarding wind energy. From 1991 to 2002 global installed capacity increased 28% annually, and wind farm costs dropped around 20% for each doubling of cumulative capacity (Junginger et al., 2005). High expectations regarding off-shore wind farms are shared internationally by networks involving the oil sector, off-shore sector, energy research institutes, electricity sector, power equipment producers, finance sector, governments and NGOs. International experience is growing, with off-shore wind farms in operation in Denmark and Sweden, and capacity on the North Sea expected to grow from around 600 MW in 2005 to several thousands megawatts in the coming two to three years. The Dutch government set a target for 6000 MW off-shore wind farms in 2020 and recently formulated a planning scheme for the North Sea which pointed out potentially suitable locations for off-shore wind farms. At the end of 2004 procedures for obtaining permits were formalised, leading to 78 concept initiatives by six consortia for 48 locations with a potential of 21000 MW. This large amount led the Minister of Economic Affairs in May 2005 to stop applications for the feed-in premium scheme for off-shore wind farms and biomass as it threatened to blow up the budget. Apparently, ceilings for maximum budget were not previously announce and it was not foreseen that attractive feed in premiums in combination with rising expectations of and preparations for off-shore wind farms could trigger such a potential rise in investments. Overall, the increasing global nature of the wind industry, and international built-up of knowledge and experiences are strong drivers for wind energy development. Specific implementation of wind energy in the Netherlands has however been strongly influenced by changes in institutional arrangements as it developed from a technology-push effort to a much broader network-based and market-oriented process.

[38] Data provided by the Wind Service Holland website, accessed on 4 July 2005 at http://home.planet.nl/~windsh/statistiek.html.

[39] Calculated from data provided by the Wind Service Holland website, accessed on 4 July 2005 at http://home.planet.nl/~windsh/statistiek.html.

4.11 The development of photovoltaic technology

Solar energy was singled out as one of the promising renewable energy technologies for the long-term after the oil crises hit in the 1970s. While the knowledge base slowly gained ground from the 1970s on, (see Table 4.5) on landmarks in PV development, a specific R&D program for solar energy was initiated in 1978, and first projects for PV were funded in the second Dutch solar energy program of 1982. In 1986 a specific R&D program for PV was started, while also industrial efforts were expanded. Universities have been important actors in developing the fundamentals of PV, later on research institutes became involved in developing and applying PV. Technological development in the eighties was mainly driven by potential stand-alone applications and has been crucial to gain experience. Grid connected PV has increased from the middle of the 1990s, through various demonstration projects partly funded by R&D programs. In some stand-alone applications PV is economically viable because of the specific niche it serves (cattle drinking systems, isolated lampposts, boats, etc.). This is also due to the characteristic of PV as a modular technology: costs per unit of small systems are comparable to costs of large systems (Sinke, 1999).

Photovoltaic (PV) solar energy was at the end of the nineties characterised by the parallel development of various technological concepts. There are several competing technologies for the production of solar cells, such as mono- or multicrystalline wafers which is basically an extension of semiconductor production techniques of the micro-electronics industry and thin-film technologies where thin layers of semiconductor material are put on a supporting substrate (Green, 2000).

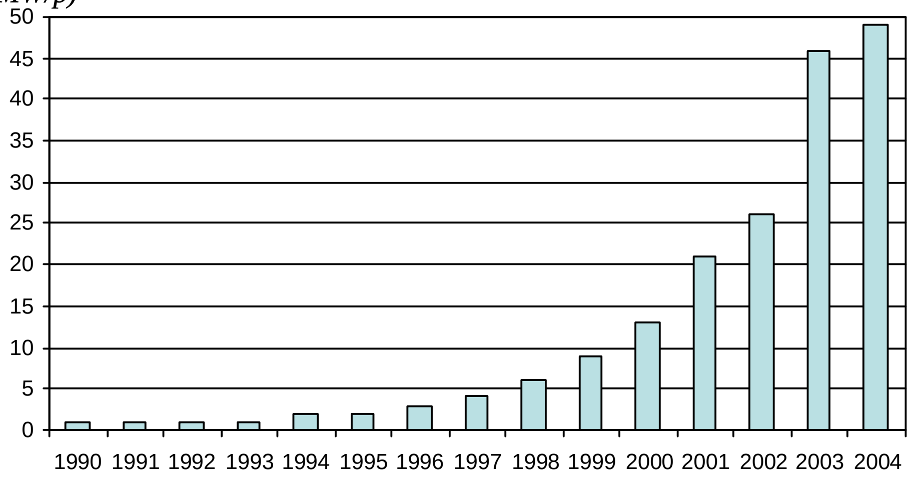
Some concepts are commercially applied such as the multi-crystalline PV module, but most are in a more fundamental research phase (Sinke, 2000). While initially developments in PV were driven by stand-alone off-grid applications, from 1994 on grid-connected PV dominates the market, made possible by the development of inverters that convert direct current of PV panels into alternating current used in the grid (Hofman & Marquart, 2001). Table 4.6 gives cumulative installed capacity of PV in the Netherlands and shows how the PV market has significantly grown from 1995 onwards.

Table 4.5 Landmarks in PV development[40]

1839	Becquerel discovers the photovoltaic effect
1954	Bell Laboratories develops PV cell with 4.5-6% electrical efficiency
1957	First PV cell in the Netherlands, at Philips Nat Lab
1958	Vanquard I satellite launched with six solar PV cells, first PV powered satellites
1963	Sharp Corporation succeeds in producing practical silicon PV modules
1970	KEMA starts research on renewable energy (three solar cell houses at KEMA grounds)
1972	TUE starts with research on PV by researcher Daey-Ouwens (transferred from Philips)
1973	PV system (1 kW) of Philips panels (French subsidiary) constructed at KEMA grounds.
1975	EU R&D program for solar PV cells
1976	Dutch branch of ISES (International Solar Energy Society, 1956) founded as interest group for PV with Van Koppen (TUE), Turkenburg (UU), and Francken (RUG).
1978	Solar energy program started (NOZ-1), focus on thermal, not on PV
1980	Holecsol produces semi crystalline cells (van Solingen), with license from Solarex (US)
	Kema builds solar panel for hospital in Tanzania (as part of development aid)
	Several research groups engage in PV research (TUE, UU, Nijmegen, Amsterdam, TUD en Amolf), not yet funded by NOW
1981	AMOLF starts PV related research program
1982	Second Solar Program (NOZ-2), with some PV projects (7 out of 46)
1982	AMOLF collaborates in PV research with Holecsol
1984	Shell starts Renewable Energy Systems, takes over personnel from Holecsol
1986	NOZ-3 with specific PV part (NOZ-PV-1)
	Collaboration Amolf with Holecsol continued in collaboration with R&S Renewable Energy Systems (now Shell Solar Energy)
	KEMA reduces PV research and focuses on standards and testing of PV panels
	Solar energy activities started at Ecofys in Utrecht
1988	Stand alone PV house in Castricum, 2.5 kWp
	Amolf approaches ECN regarding PV program
1989	First grid-connected PV system in the Netherlands (1.2 kWp) operational at ECN
1990	Government R&D Program NOZ-PV-2
1991	First 10 houses with grid connected PV in Heerhugowaard (Novem and Pen)
1994	AC module developed (with Ac-Dc inverter) ; All electric zero energy house with 3.3 kWp
	Consultancy platform PV is formed
1995	Housing district in Nieuw Sloten with grid connected PV (250 kWp)
1996	First professor in PV technology (Sinke)
1997	PV covenant concluded between various actors and government
1999	Shell Solar Energy formed as follow up from R&S
1999	ECN forms business unit Solar Energy (around 50 people)
2000	1 MW PV project at Nieuwland (REMU, Ecofys, Novem, EU, a.o.)
2002	2.3 MWp solar roof installed at Floriade (NUON, Siemens, Shell Solar, Econ. Affairs)
2003	Installed PV rises with 80%, particularly through private panel owners
2004	Dramatic drop in PV growth as various subsidies are discontinued; re-orientation of PV policy on R&D

[40] Sources: Sinke, 2000; Knoppers, 2000; Kruijsen, 1999; PV Power, The history of PV, available at website http://pvpower.com/pvhistory.html.

Table 4.6 Evolution of installed capacity of PV in the Netherlands[41] *(in MW/p)*



Several observations regarding PV development and implementation can be made. PV technology has been able to develop through a process of niche cumulation:

- Early developments and applications for PV originate in space programs (first market niche), with NASA and US companies as driving actors, and were also facilitated by research from the electronics industry on semiconductors;
- The oil crisis directed attention towards potential for power production, early applications are mainly stand-alone DC systems (second market niche);
- Grid connected systems increased when AC-DC conversion was facilitated, although connection to the grid incorporates extra costs as compared to autonomous systems (third niche);
- Building-integrated PV has become the major market for PV in the past decade. Efforts have resulted in cost reductions, performance improvements, the development of new integration products and the creation of a network with utilities, property developers, architects, building companies and local authorities (Schoen, 2001).

Also the network of actors involved in PV has significantly broadened in the past decade. The main developments can be characterised as follows:

- In early projects, frontrunners regarding PV application such as the energy companies of North-Holland and Amsterdam were driven by

[41] Data based on CBS (2004) except for 2004 data from the International Energy Agency website, http://www.oja-services.nl/iea-pvps/isr/index.htm, accessed 4 July 2005.

visions of pioneers[42], later on distribution companies become more strongly involved in solar energy in order to reach CO_2 and renewable energy targets set in the environmental action plan;

- The PV network has emerged relatively bottom-up in the Netherlands, a PV group (1991/92) and later platform (1994/95) was founded to discuss the scope for development and implementation of PV. In its application phase PV demands the collaboration of various actors as the systems are currently mostly integrated in housing projects. This formed the basis for the PV covenant that was in 1997 concluded between PV R&D groups, consultancy firms, energy companies, real estate developers and architects. In this sense the PV network was structured by the conditions needed for implementation, and less by the funding provided by government as was the case for wind, although the new formulated PV program of 1997 with doubled budgets relative to the previous program was in incentive;
- At the demand side, Greenpeace plays a role through its Solaris project, that aims to generated large scale demand for PV modules, based on the assumption that large scale production will significantly drive costs down;
- Dutch industry has played a mixed role in PV development. Shell Solar is involved and had significant production capacity but closed down its production facility for PV modules in Helmond in 2002 and shifted production to Gelsenkirchen, Germany. Philips is involved in inverter production and Akzo Nobel in R&D on thin-film technology and production;
- Oil companies such as Shell and BP increasingly are becoming energy companies that expect a large potential for PV technology in the medium to long term. Shell Solar was, through its subsidiary R&S among the first industries to enter the PV-platform, in 1999 BP joined through its subsidiary SolarNed (Van Mierlo, 2002: 301).

An interesting policy development took place for photovoltaic technology in 1997 when the Dutch Ministry of Economic Affairs published its vision on sustainable energy in “Renewable Energy – Advancing Power” (EZ, 1997). In this document, photovoltaic technology was considered to be the most important option for electricity generation in the long term, and could be expected to break through from 2020 on. Efforts were thus concentrating on providing a path facilitating and preparing for this breakthrough. The document also provided the starting point for the set up of a PV covenant between various actors involved in the production and use of PV modules.

[42] Activities of these energy companies can partly be explained by the strong involvement of pioneer Daey Ouwens in his work at the province of North-Holland (Knoppers, 2000).

Parties involved are government, distributors and their organisation EnergieNed, PV-industries, construction industries, ECN and Novem. In the covenant it was declared that they would make PV a competitive as an energy source for the 21st century. Budgets for PV increased significantly from 1997 to 2000 to annual averages of around 19 million Euro from annual averages around 5 million Euro in the period 1990-1997 (Van Mierlo, 2002: 227). The focus shifted from fundamental research to pilot projects and market introduction. The support system was fundamentally changed in 2001 as the specific R&D programme for PV was terminated. Only for off-shore wind and biomass specific programmes remained as they were expected to significantly contribute to the target of 10% renewable energy in 2020. In a more broader renewable energy R&D programme for PV could compete with other options for support. The most important change was the inclusion of PV in the energy premium regulation which covered around half of investments in PV modules (Van Mierlo, 2002: 229). This led to thousands of customers buying small PV panels (IEA, 2003). This process was abruptly stopped at the end of 2003 when support through the energy premium regulation was cancelled by the new government coalition and a stronger R&D orientation was re-introduced. The result was that in 2004 the PV market in the Netherlands fell dramatically. Total installed capacity in 2004 was only one-fifth of that in the previous years. Changes in policy were responsible for this reversal. The so-called energy premium policy, under which solar panels were eligible for investment subsidies, was abolished, and utility subsidies for private panel owners ended due to the change from demand oriented exemptions for the regulatory energy tax towards feed-in premiums. As a consequence, several actors withdrew from the PV market and many project developers and contractors shifted their focus to foreign countries, in particular Germany (IEA, 2005).

What this last example indicates is the way policy measures can reinforce ongoing dynamics. Similarly, policy measures can also dampen dynamics as in the case for solar energy, where changes in policies slowed down the growth rates of installed PV capacity dramatically. The main motivation of the Minister of Economic Affairs is that PV is not feasible, can not contribute significantly in the short term, and has no industrial priority, arguments which significantly diverged from the position of the Ministry in 1997, when strong long-term potential of PV was emphasised. Other countries have developed rather different cycles of expectations, approaches, and policies, such as the policy of Japan, where the aim is to produce 50% of power with PV by 2030, where capacity topped 1000 MW in 2004 with 270 MW installed in that year, and where a range of companies, mainly from the semi-conductor and electronics sector, have become top producers of PV.

The main point is to point out that expectations, approaches, and policies have a tendency to co-evolve with industrial and institutional changes. Liberalisation has introduced a short-term market orientation both in the electricity sector and in government circles which tends to lock-out PV. However, PV development was rather strongly connected to diverse networks where private panel owners, housing associations, building project developers, and municipalities played central roles next to energy providers. PV is therefore also taken up increasingly in the realm of building, whereas its policy support is dominantly related to energy development. This is an example of the way broader institutionalisation impacts the choices and strategies regarding technologies such as PV that will provide different functions than traditional energy technologies.

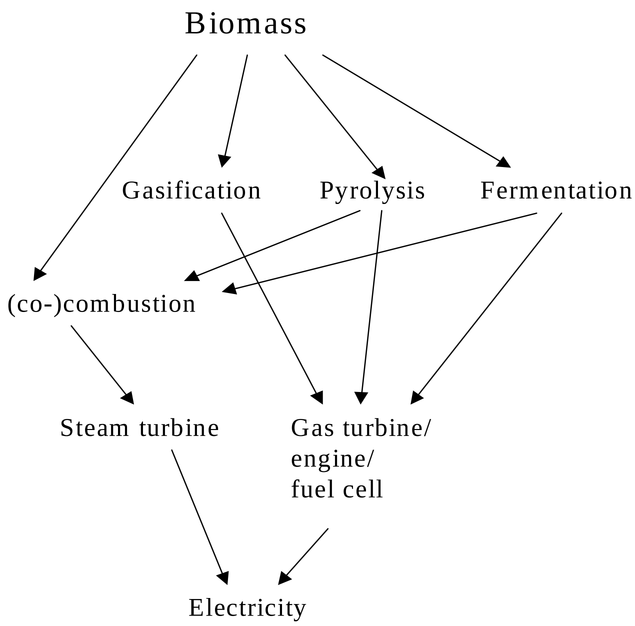
4.12 Biomass[43] emerges as the dominant sustainable variety

Biomass can be applied in various ways as a source for electricity generation. Four dominant principles exist in the route from biomass to electricity, Figure 4.5 gives an overview.

Combustion is the principle dominantly used because it applies the same technologies as in conventional electricity generation. For three other routes, gasification, pyrolysis and fermentation/digestion, biomass is first converted to gas or oil before it is fitted into electricity production with steam turbines and/or gas turbines. These routes are generally considered to have larger potential in the long term because they can provide more efficient and cleaner electricity, but also because bio-fuel is a potential fuel source for the transport sector.

[43] Here we use the term biomass to indicate renewable sources based on organic material (short-term carbon-neutral cycle). In this section we also characterise waste as biomass. The non-fossil part of waste is considered as renewable biomass, and the fossil part, such as plastics, is considered non-renewable. Although EU policy initially suggested that waste incineration did not fall under biomass, after intensive lobbying of especially the Dutch, it has accepted the organic fraction of waste as renewable energy.

Figure 4.5 Conversion of biomass into electricity (Faaij, 1997)



Until the middle of the eighties the use of biomass for electricity generation was limited. In the late 1980s, the use of biomass as a source for electricity production increased when the first national environmental policy plan introduced a new sequence of waste treatment options, preferring waste incineration to disposal. Waste disposal became increasingly questioned because of lack of space and soil pollution in the Netherlands. Also the use of waste incineration for heat and/or electricity production was formulated as a policy objective (VROM, 1989: 223). Consequently, waste incineration expanded and increasingly electricity generation was added as an additional activity. Next to incineration also the use of landfill gas for electricity generation increased. From 1995 on, electricity production by waste incineration significantly increased (see also Table 4.7), due to increasing restrictions on waste disposal and the introduction of regulatory measures for incineration plants that forced existing installations to reduce emissions and increase efficiency, thus also increasing electricity production. Waste incineration was until the end of the nineties the main renewable source for electricity generation but remained at a stable level while other biomass options were expanding, particularly co-combustion of biomass in coal-fired power plants. In 2003 around a quarter of Dutch renewable energy is based upon waste incineration (CBS, 2004: 25).

Table 4.7 Waste treatment routes in kg waste

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Compost	1400	1500	1500	1500	1490	1568	1448	1444	1361
Incineration	2800	3550	4350	4550	4905	4982	4855	5087	5180
Disposal	9800	8450	7400	7100	7600	6550	6530	5157	4777

Source: VVAV, website, 2000 and 2005.

From the end of the eighties on also the other routes for biomass as an energy source are increasingly explored. Gasification and fermentation are currently technologically proven concepts, and have been commercially applied. For gasification BTG has done pioneering work from the end of the seventies on, through the development of small-scale gasification systems applied in developing countries. Moreover, BTG is currently also involved in upscaling of pyrolysis technology[44]. Know-how regarding fermentation has been traditionally strong at the Agricultural University of Wageningen[45]. The emergence of several programs for biomass R&D[46] initiated biomass related energy projects at research institutes and led to strong competition between the three major energy research institutes in the Netherlands, Kema, ECN and TNO[47] (Veringa, 2000). At the end of the nineties biomass has become the second largest beneficiary for R&D funding in renewable energy, with 9 million euros in 1998 and an 11 million euros in 1999[48].

From the various renewable energy sources, biomass has been the only source also significantly applied by the electricity production sector. Co-combustion of biomass is increasingly applied in coal fired plants. The main reason is that coal-fired plants have become more and more unattractive because of their high CO_2 emissions. Government pressure to improve environmental performance of power plants has increased in the end of the nineties, even leading to suggestions that coal-fired power plants should be closed down, see the text box on the following page. However, in 2000 an agreement was reached to reduce CO_2 emissions of coal-fired power plants by 6 million tonnes in 2010 relative to 1990. This should be realised by co-

[44] Based on the rotating cone reactor for flash pyrolysis for which BTG has a patent. Exploiting economies of scale is the current focus of BTG's projects. See website of BTG at http://www.btgworld.com/.

[45] At LUW professor Lettinga has been one of the early pioneers in this field from the seventies on. Lettinga's name is mainly associated with the development of anaerobic water treatment systems, but is also involved in R&D on anaerobic digestion of waste.

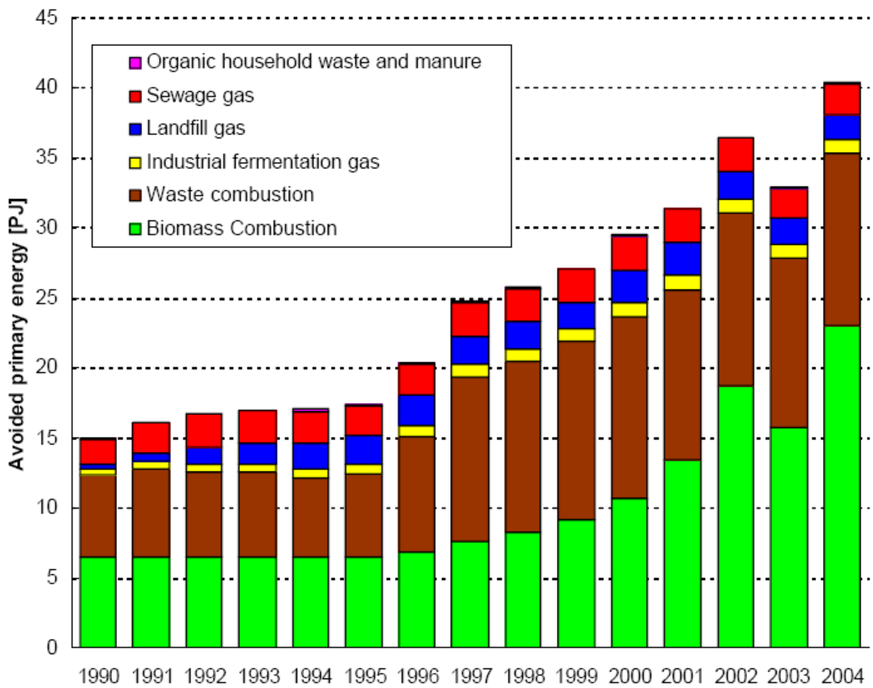
[46] The EWAB program (Energy from Waste and Biomass), started in 1989 and was managed by NOVEM.

[47] As of 1997 TNO is affiliated with BTG through a significant participation.

[48] Overzicht van publiek gefinancierd energie onderzoek in Nederland, 1997, 1998, 1999, Novem (2000).

combustion of biomass, increased efficiency and CO2 storage in forests[49]. Another positive incentive for electricity production through co-combustion was the fact that the 'biomass' combustion part was considered 'green' electricity, and eligible for exemption of the regulatory energy tax (ECN, 2000: 58). After the change in the support system for renewable energy, co-combustion became eligible for a feed-in-premium.

Figure 4.6 Evolution of various biomass forms in the Netherlands (Junginger and Faaij, 2005: 8).



Overall observations regarding biomass development are:

– Biomass as a renewable energy source is generally seen as the most promising option for the near to medium term, due to its technologically mature and economically viable characteristics;
– The dominant applications by the electricity sector are combustion and co-combustion because they are a good fit with incumbent technologies and competencies;
– Other conversion routes, such as gasification, fermentation, pyrolysis are more driven by actors outside the traditional electricity sector, some of them are in the early commercial phase;

[49] Nieuwsblad Stromen, 23 juni 2000, p. 3.

- Conditions and developments in other regimes (waste regime, agricultural regime) play a significant role in the development of biomass as an option for electricity generation;
- The agenda and expectations for use of bio-fuels for the transport sector are increasing, also due to EU guidelines and this increases competition between biomass utilisation in the power and transport sector.

In overview, biomass is a very diverse and fragmented source for electricity generation. There is fierce competition for R&D budgets between conversion routes that are not yet commercial. For commercial routes, especially combustion and co-combustion, there is also strong competition for biomass sources, such as for waste-wood. For example, the energy distribution company Essent acquired first mover advantage in its development of the Cuijk biomass-fired power plant for which it agreed on contracts with for example Staatsbosbeer, for wood prunings, and with sawmills for wood remains (Hofman, 2005). The company Electrabel announced in 2001 that it had bought all olive residuals from Tunisia as a potential product for co-combustion but this can only serve some percentage points of its total biomass demand (Penninks, 2001). In 2003 and 2004 imports of biomass grew rapidly, mainly agro-residues, palm oil, olive residues, palm kernel, etc., and it was estimated that around 50% of co-combustion took place with imported biomass, with several power plants importing all biomass for co-combustion (Junginger and Faaij, 2005: 16, 20).

This is illustrative for the way the logistics and availability of biomass is given shape in an international setting and demands altogether new linkages and networks, but also points at major uncertainties regarding the way a biomass market may unfold. One of the uncertainties is the way appropriate institutional arrangements can evolve to safeguard the sustainability aspects of biomass crop production and international biomass trade and its effects on land use and agricultural crop production. Some studies have suggested that local production and use of biomass for power and/or transport may provide positive effects to local economies relative to imports of fossil fuels (Van den Broek, 2000). Institutional frameworks need to ensure that income is not mainly appropriated by elites and that local food production or tropical forest areas are not threatened. For example, Essent has been involved in the development of a certification scheme to ensure that imported biomass for co-combustion can be traced, and to ensure that certain sustainability principles are being followed by suppliers (Junginger and Faaij, 2005: 23). Also a taskforce on sustainable bio-energy trade at the International Energy Agency has been set up to specifically to develop and disseminate information and knowledge for the creation of sustainable bio-energy markets.

The focus on biomass based electricity generation is often strengthened by its link to other policy fields, such as its role to close material cycles in waste policy and manure policy (see also Raven, 2005). Due to its various conversion routes, the various applicable sources and its links to various policy fields there is also a multitude of actors involved in biomass development, all with specific (different) agendas. Biomass has taken an important position in transition routes and the recently developed research agenda of Economic Affairs. Co-combustion of biomass in coal-fired power plants has become the main route, and its evolution is characterised by strong involvement of incumbent power producers after the covenant on CO_2 reduction was agreed and after the electricity produced through biomass co-combustion became eligible for the exemption of the regulatory energy tax and later the feed-in premium.

4.13 The introduction of 'green' electricity

Consumers played a relative passive role in the electricity system until the nineties. Whereas the role of industrial users increased with the emergence of decentral combined heat and power production, households were 'captive' consumers (no choice, fixed prices) of electricity until well in the nineties. Several developments, however, have facilitated changes in this mode of provision. They include the changes in law concerning the electricity market structure in 1989 and 1998 (two new electricity acts) and demands from the government towards distribution firms with regard to the attainment of certain environmental goals. From the middle of the nineties on PNEM was the first energy distribution company to make a distinction between renewable and non-renewable electricity in marketing (Hofman, 2002). For the so-called 'green' electricity consumers pay a premium, which compensated the higher purchase price the distributors paid to providers of 'green' electricity. In anticipation of liberalisation energy distribution companies had become much more customer oriented and focused on its product and marketing. Crucial is the way the concept involved a new institutional arrangement with new roles for green electricity producers, an environmental NGO, and consumers, which received swift support from government, and spread rapidly as other firms started to imitate the concept. Chapter six provides a detailed analysis of the emergence and diffusion of the concept and institutional arrangement.

4.14 Conclusions

Table 4.8 provides an overall assessment of the various paths taken in the electricity system. The paths are discerned regarding the level of divergence from the fossil-based central station electricity regime. The table suggest that options that could be integrated with least difficulty have, not surprisingly, had reasonable success. The current expansion of co-combustion can also be explained by the low level of divergence with the fossil-based central station electricity regime. The initial uptake of coal gasification also follows this logic, but the lack of success has had to do with the erosion of the principle of being able to transfer long-term investment costs onto consumers. Thus, institutional change has reduced the potential for coal gasification, although it can be expected that, with increasing success in other countries, it will return as a serious option in the Netherlands in due time. The most interesting outcomes of the overview are the success of decentral cogeneration and green electricity. Despite high divergence these paths have been relatively successful. The next chapters will provide an in-depth analysis and explanation for this.

Table 4.8 Overview of paths taken in the electricity system

Path taken	Relative success	Shift in resources	Shift in mode of production	Shift in mode of provision	Shift in use
Shift from coal to gas	++	Yes	No	No	No
The nuclear route	-	Yes	Yes	No	No
Hybridisation of gas and steam turbines	++	No	Yes	No	No
Coal gasification	-/+	No	Yes	No	No
Distant heating	+/-	No	No	Yes	Yes
Decentral cogeneration	+	No	Yes	Yes	Yes
Wind power	-/+	Yes	Yes	Yes	No
Solar power	-/+	Yes	Yes	Yes	Yes
Biomass co-combution	+	Yes	No	No	No
Biomass combustion	-/+	Yes	Yes	No	No
Waste incineration	+	Yes	No	Yes	No
Biogas cogen	-/+	Yes	Yes	Yes	Yes
Green electricity	+	Yes	Yes	Yes	Yes

Let us consider other factors that can explain rate of success or failure. An important outcome of all paths was the impact of the nature of institutional arrangements. Table 4.9 provides an overview of relative success of paths in time periods characterised by different institutional arrangements within the electricity sector, and significant change in the perception of its institutional logics as triggered by the oil crises. Some paths were frustrated under monopolistic conditions, while uptake was stimulated when competition was introduced. Here, the pattern is reasonably coherent. Before the oil crisis the nuclear route perfectly fitted institutional logics of the electricity regime and the broader societal substructures. Processes of re-institutionalisation had been underway for decades to facilitate integration of nuclear power into the electricity system, as the knowledge infrastructure was geared to nuclear knowledge generation, political support was high, and the economy was expecting continued low-cost electricity. Towards the end of the sixties, societal opposition was already starting to show, and this was accelerated due to the oil crises. But most importantly the dominant institutional logics came under scrutiny as economic growth as well as energy consumption growth stagnated. In combination with dependency on fossil fuels, and perceived finity, this triggered a search process for alternatives. The paths most close to the system enjoyed highest success, but this changed as competition was introduced in the course of the eighties. In combination with the environmental commitments by electricity distributors, a range of alternatives were moving forward. The process of liberalisation has facilitated the emergence of new entrants in the electricity sector that were committed to moving these alternatives further, and could adapt to the institutional logics of green electricity to expand.

Table 4.9 Success of paths under different framework conditions

Path taken	Before oil crisis	Oil crises 1973-1989	Transition period 1989-1998	Liberalisation, after 1998
Shift from coal to gas	++	+/-	+	+
The nuclear route	+	+/-	-	-/+
Hybrid gas and steam turbines	+	+	+	+
Coal gasification	-	-/+	+	-
Distant heating	-	+	+	+
Decentral cogen	-	+	++	+/-
Wind power	-	-	+	+
Solar power	-	-/+	+	+
Biomass	-	-	+/-	+/-
Green electricity	-	-	+	+

Nevertheless, the rather close fine-tuning of the knowledge infrastructure to the institutional logics of the pre-crisis period has left its imprint on the development paths of renewable energy. R&D efforts have been dominated by the tendencies of centralisation and closure. Whereas the oil crisis initiated the development of a R&D energy infrastructure in the Netherlands, energy R&D policy networks of Novem, ECN, and EZ were aligned with SEP and were mainly focussed on developing a course of further large scale development of generation units, as is shown in the cases of nuclear energy, coal gasification, and wind energy. R&D activities by the electricity sector have always been defined from the basic principles of the system, and with the conviction that only the sector knows how to handle electricity production in the electricity system, with other actors not being able to live up to their standards. This has led to a relatively closed arena of R&D in the electricity sectors, with SEP and KEMA as main actors, few other actors significantly involved and virtual non-existence of interaction with societal groups.

The dominant institutional logics also showed in R&D strategies by the government that long breathed the belief that the course of technological development and diffusion was malleable, as the (early) experiences with nuclear energy and wind energy. What stands out is that the path of technological development is not very well embedded in society, because of a lack of institutions that play a role in adapting the technological configuration to society and in use of electricity. It is foremost a technical top-down effort, isolated from societal influences. It is technical in the sense that the emphasis on the artefacts is dominant (technical design, technical standards, etc.) with engineers and technicians dominant, but it is also technical in the sense of the decision making process surrounding processes of choice for R&D and implementation of projects. The organisation of R&D is very much centralised in the Netherlands, both in terms of structures for funding and in terms of research institutes. This has led to a path of technological development of alternatives where technology is often developed without participation of users and related groups. For example in the case of the development of wind energy, the initial technological development has been virtually independent of important actors such as municipalities, local users and environmental groups. Often cited success factors for the introduction of wind technology in Denmark for example, have been the bottom-up development strategy because of strong involvement of grass-root energy movement and the development of local networks involved in the actual development of the wind technology configuration (Jorgensen and Karnoe, 1995).

In overview, a main conclusion is that the dynamics of each path is rather specific, related to the characteristics of the technology, and dependent on varying processes of institutionalisation and mobilisation of actors. Each path also has its specific relationship with the dominant electricity system and has been involved in specific processes of re-institutionalisation. The most successful cases were based upon a balance of being able to develop broad expectations based on a specific vision how to realise them; bottom-up network building supported by policy and policy network strategies; and learning processes characterised by interaction between actors, and leading to adaptation of rules to further facilitate progress of the path. Table 4.10 characterises these processes for paths based on renewable energy and cogeneration. The next chapters on decentral cogeneration and green electricity will provide a more in-depth analysis of the nature of successful processes.

Table 4.10 Characteristics of development processes of various paths

Path taken	Expectations & Vision	Network strategies	Learning
Decentral cogen	Rather specific vision developed by societal groups and supported by industry and industrial policy	From bottom-up strategy to alignment with policy network strategy rather effective	A sequential process where general principles were effectively redesigned for various branches matched by changes of rules; crucial roles for intermediaries
Wind power	Unspecified high expectations received backlash; later more specific modest expectations for wind on land realised; high expectations for off-shore wind developed	Top-down strategy failed; bottom-up strategy survived and strengthened when policy network strategies were initiated	Rather robust guiding principles for scaling up emerged; Increasingly effective interaction between governmental layers through learning by interacting
Solar power	Long term vision initially successfully developed by PV network, later rejected by government	Integration of R&D networks with bottom-up networks successful with initial policy support	Learning by interacting and doing initially successful; some rule change initiated; later lack of alignment of actors
Biomass	Broad expectations about variety of routes and resources; later more specific focus by market and policy	From rather diverse bottom up networks to networks more dominated by central station logics	Strong R&D learning about potential resources, logistic and routes; learning by doing of market parties
Green electricity	Expectations rises as concept is successfully launched; integrated in demand-oriented vision	Bottom-up network effective in gaining industrial and policy support	Market actors learn regarding potential of user orientation and green segment

Chapter 5

Evolution of decentral cogeneration in the Netherlands

5.1 Introduction

This chapter focuses on the development of decentral combined heat and power production, in short: decentral cogeneration, in the Netherlands. The development of Dutch cogeneration is remarkable because of the high penetration within the Dutch electricity system, and because of the rapid uptake of decentral cogeneration from the mid eighties to the end of the nineties. From a comparative perspective it is salient because the share of decentral cogeneration of around 40% is high relative to the EU average of around 10%. In countries such as Germany, the UK, Belgium and France the share of cogeneration is lower than 10%, while cogeneration in Denmark and Finland has a share in electricity generation comparable to the Netherlands. The main relevance of decentral cogeneration for this thesis lies in its character: it represents a fundamentally different way of electricity generation, both in the way it is perceived to fulfil the function of energy provision as in the way this function is organised. Decentral cogeneration implies a different actor constellation with different roles for actors as compared to the central station electricity system[1], such as for example the stronger user orientation due to the importance of heat demand within the cogeneration package. It demands different types of knowledge because the topology of the network changes as electricity flows become more heterogeneous and as heat demand determines the location of power plants. Different planning procedures and regulations are required as more entry points and units for electricity generation emerge within the system and its network infrastructure, with more heterogeneity in supply profiles. Decentral cogeneration is mainly dimensioned along local demand for heat, which implies that its optimal scale is dependent upon, and varies according to, the heat demand profile of the user(s). In short, it requires a different

[1] The central station electricity system involves generation of electricity in a power plant and transport and distribution through a power network to a variety of users.

technological and institutional configuration of the system compared to the central station model.

The main topic in this chapter is how, why and which change processes were set in motion enabling the fast rise of decentral cogeneration within the Dutch electricity system. Data sources include an extensive body of research on the development of cogeneration, primary data regarding the development of cogeneration capacity and production, earlier research of the author (Arentsen, Hofman and Marquart, 2000; Hofman and Marquart, 2001), and interviews with key actors. The main purpose is not to repeat the multitude of studies analysing the development of cogeneration but foremost to apply and develop a specific analytical perspective. This perspective is explained in section 3, following the presentation of basic data regarding the development of cogeneration in section 2. Sections 4, 5 and 6 focus on the emergence, fast rise and stagnation of cogeneration respectively. In section 7 the analytical perspective is applied and further refined based on the analysis of main patterns of change in decentral cogeneration. The chapter ends with a concluding section.

5.2 Basic data on the development of cogeneration in the Netherlands

As Figure 5.1 shows the development of decentral cogeneration has a distinct character with a rather stable share to the middle of the eighties in the total mix of electricity production capacity in the Netherlands. This changed towards the end of the eighties as the share of decentral generation steadily grew with annual investments of around 60 to 200 MWe in the period 1985-1994 and of around 400 to 625 MWe in the period 1995-1999. From 2000 investments in decentral cogeneration stagnated and some installations were shut down. This pattern is even more pronounced for the amount of electricity generated based on cogeneration. Figure 5.2 shows an accelerating increase in production through cogeneration from the middle of the eighties and Figure 5.3 shows the increase the share of decentral cogeneration in domestic electricity production from 10% at the end of the seventies towards 36% in 1999 and 2000, with a drop to 31% from 2001 to 2003.

A look at the nature of the technology used for cogeneration shows a shift from larger scale steam turbines towards combined cycles, diverse scale gas turbines and small gas engines. In terms of capacity combined cycles start to take the dominant share in the course of the nineties (Rijkers et al., 2002).

Figure 5.1 Development of central generation and decentral cogeneration capacity in the Netherlands (Sources: EnergieNed; Ministerie EZ, 1980; SEP/VEEN/EnergieNed, 1989).

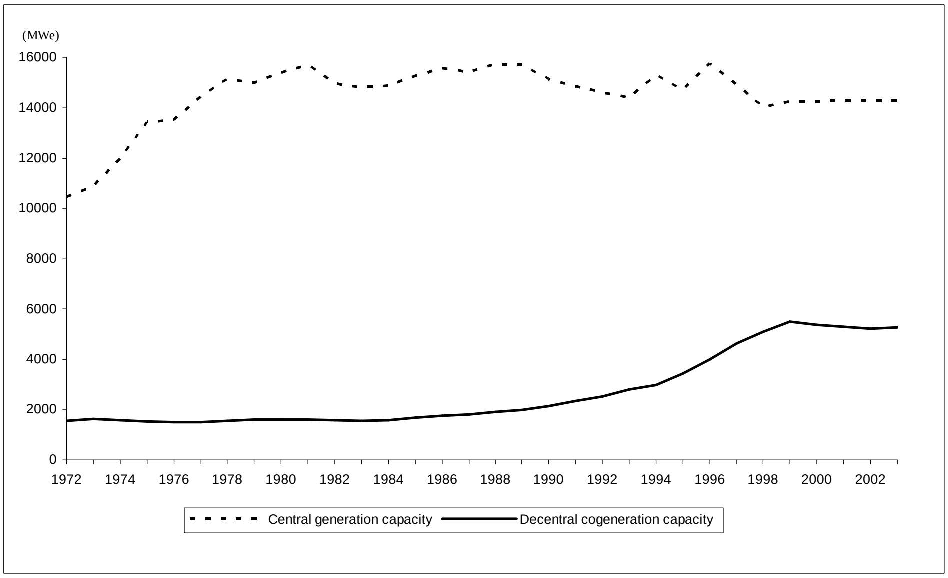


Figure 5.2 Evolution of origins of Dutch electricity (Source: EnergieNed).

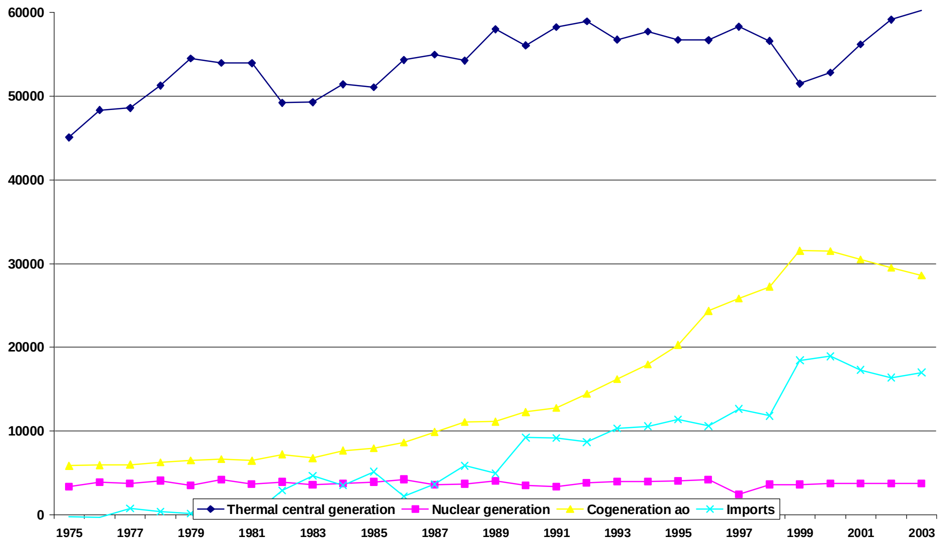
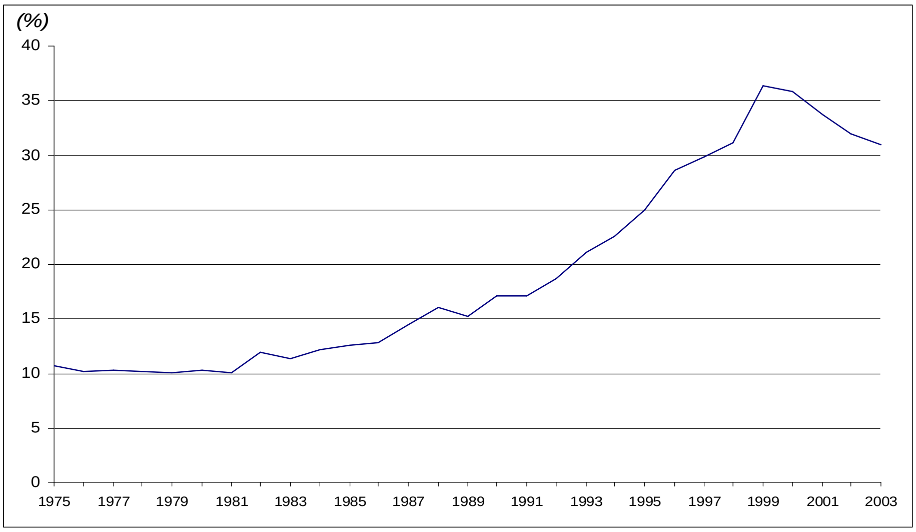


Figure 5.3: Share of decentral cogeneration in domestic electricity production (EnergieNed)



The increasing diversity of types of technologies used can be explained by a similar increasing diversity in the application of cogeneration in different sectors, such as horticulture, health care organisations, service organisations, wastewater treatment plants, swimming pools, hotels, and so forth. Changes in the nature of investments can also be observed. Historically investments in decentral cogeneration took place in various industries[2] as a means to produce electricity and heat for own use. From the end of the eighties on a new actor becomes a major investor in decentral cogeneration: the energy distribution sector. The amount of cogeneration capacity under control of energy distributors increased from 70 MW in 1990 to 950 MW in 1996 (Elzenga et al., 2001). Moreover, energy distributors started to invest in cogeneration through joint ventures with industry. Joint-ventures took a share of 28% in decentral (co)generation in 1995, and this share expanded to 48% in 2000 and 47% in 2003[3]. A further pattern of change is a development towards cogeneration installations producing a larger share of electricity for the grid relative to own use. Early installations, before 1985, were more dimensioned based on own electricity demand because of relatively low remuneration tariffs (Battjes and Rijkers, 2000). As the climate for cogeneration improved, for example through subsidies and higher

2 Mainly process industries with a continuous demand for steam such as the chemical industry, paper industry, food industry and petrochemical industry (SEP, 1979; Blok, 1993).

3 Source: Central Bureau of Statistics, the Netherlands, Decentrale elektriciteitsproductie naar sector, in: CBS, Energie and Water.

remuneration tariffs, the share of installations dimensioned on heat demand increased with as a result more electricity produced for the grid.

5.3 A perspective on institutional change

For understanding the development of decentral cogeneration we use a perspective in which decentral cogeneration is perceived as the emergence and spread of an alternative technological and organisational form in the larger context of the electricity system. In the early 1970s steam turbine technology, the central station electricity system, and organisation through regional monopolies were technological and organisational forms firmly rooted in the electricity system. The structure, practices and exchange relationships had been stable and taken for granted in the post-war electricity system and the main concern was the security of supply. The prevailing institutional logic, defined as a set of socially constructed assumptions, values, and beliefs (Sine and David, 2003: 185), was based on a 'growth dynamics' paradigm based on increasing efficiency through expansion (allowing more efficient, larger scale, turbines) in which the system derived its legitimacy from enabling economic growth through expansion and cultivation of energy supply and consumption (i.e. energy growth equates economic growth equates progress) and its credibility through providing stable and affordable prices for all. In the light of high energy growth rates the dominant expectation was that nuclear power was 1) a perfect fit to allow further expansion of the system, 2) could increase stability[4] of the system by allowing even more stable prices and reducing fossil dependency, and 3) was a good match to the existing engineering and economic principles of the system.

This institutional logic, which synchronised action within the electricity system, also strongly affected the nature of the linkages with broader systems in society: the knowledge infrastructure; the policy system (involving politics and policy); the economic system; and society at large. The extent of institutionalisation of the nature of these linkages is analysed elsewhere, and we suffice with an overview of a typology of these linkages, presented in Table 5.1 (in the first column). The main point here is that a high degree of institutionalisation can be observed for the linkages of these areas to the electricity system in the early 1970s, examples are presented in the second column of Table 5.1, such as for the structure, R&D direction,

4 Nuclear power offered lower variable costs than fossil based power, high investment costs were absorbed through the monopoly model, and it was expected to reduce geopolitical dependence on volatile regions.

and search routines in the knowledge infrastructure that were strongly intertwined with the technological and organisational nature of the electricity system. In the economic system the mode of provision for electricity was mostly taken for granted, with the exception of larger industries producing electricity in-house. With regard to the linkages with the political and policy system, organisation through natural monopoly was unquestioned, and goals and problem perceptions of the electricity sector and government were congruent in the sense that facilitating growth of energy supply and consumption was seen as intrinsically linked to economic growth. The concern of long-term security of supply was expected to be solved by a changeover to nuclear energy. Congruence between goals, problem perceptions and solutions was also facilitated by rather closed circles of interaction, with energy policy making restricted to actors in the electricity sector, oil and gas sector, and the largest industrial companies in the Netherlands[5]. With regard to the linkages to society, electricity was mostly taken for granted and did not receive a significant level of public scrutiny. The mode of communication with society was rather one-sided, and mainly involved information campaigns regarding potential uses of electricity (VDEN, 1977). Towards the beginning of the seventies a public relations strategy was initiated by electricity organisations to respond to increasing negative and weakly founded publications regarding electricity production and distribution. The goal was to provide objective information about electricity, with a strong technical focus on issues of supply and distribution, in order to refute subjective and ill-founded representations of the functioning of the electricity system (VDEN, 1977: 128-129).

In chapter three we presented main concepts for the investigation in the empirical chapters. The focus in this chapter is on understanding the interaction between corrosion of dominant logics, de-institutionalisation of the embeddedness of the electricity system in societal substructures, and institutionalisation of the alternative path of decentral cogeneration, and the way this has shaped the evolution of decentral cogeneration and its fast rise in particular.

5 Regular meetings took place between the largest six industrial companies in the Netherlands (Philips, Hoogovens, Akzo, Unilever, Shell and DSM) and the Ministry of Economic Affairs where energy was discussed among a range of issues.

Table 5.1 Typology of linkages of production-consumption systems to wider societal subsystems and the nature of their institutionalisation in the early 1970s

Subsystem – type of linkage to production-consumption system	Nature of institutionalisation for the electricity system
1) Economic system	
- mode of coordination	Set of rules regarding grid connection, parallel power production, back up power, hampers power delivery to the grid for actors outside the electricity sector
- industrial organisation	Monopolistic organisation of e-sector hampers emergence of alternative organisational forms for electricity generation and provision
- mode of provision	External electricity provision taken for granted in industry; tariff structures supportive for larger consumers, energy-intensive industry.
- perception of nature of problems – solutions	Electricity costs and reliability are main issues for industry, generally accepted that this is the responsibility of the electricity sector and trust in their ability to secure long-term supply and solve related problems. Only dissent from VKW (association of self-producers) who argue that industrial self-production is in various cases more efficient
2) Knowledge infrastructure	
- mode of coordination	Support structures, information flows, and advisory committees strongly dominated by proponents of the system: no support for, and information flows about, alternative technologies and designs
- mode of organisation	Educational and research organisations linked to central station electricity system: alternative designs overlooked and rarely educated and investigated
- perception of nature of problems – solutions	Main problem of securing long-term supply solved by changeover to nuclear power, alternatives are overlooked and rarely investigated
3) Policy system	
- mode of coordination	Acceptance of natural monopoly for electricity as public good; high autonomy for electricity sector in setting prices and contracts; major role policy on resource inputs
- organisation of policy	Energy departments reflect fossil resources, nuclear energy and focus on supply for economic growth
- mode of communication	Strong interaction with electricity sector regarding energy issues
- relation to political, societal goals	Congruence between goals of sector and government
- perception of nature of problems -	Enabling the 'growth dynamic' paradigm to continue

solutions	is main concern: focus on security of supply and nuclear power as solution
- R&D policy and orientation	Single focus on nuclear R&D; nuclear research institute plays core role; focus on securing energy supply to facilitate industrial growth
4) Society	
- mode of coordination	Electricity is taken for granted, seen as public provided good, system is intertwined with daily life (‘electrification’)
- mode of communication	Electricity system presented as objective, technical reality; one way information flows to educate citizens on use; technical responses in reaction to subjective opinions (e.g. concerns regarding cooling water, nuclear safety)
- perception of problems	Rather low public scrutiny and involvement regarding the workings of the system; main focus on securing long-term and reliable supply

5.4 Foundations for change: understanding increased attention for cogeneration

Corrosion of the growth paradigm of the existing system

Although the upturn in decentral cogeneration started to show from the middle of the eighties, the stage was set by a range of earlier events and developments that impacted basic aspects of the electricity system. Table 5.1 provides an overview of major policy milestones and other developments that have impacted the course of cogeneration in the period 1972-1983. What these developments had in common was that they corroded the taken-for-grantedness of the existing sociotechnical configuration. The growth paradigm[6] was increasingly challenged as the effects of two oil crises unfolded, environmental concerns were voiced[7], and national government aimed to increase control on the electricity system. Instead of focusing on

[6] In a report on nuclear energy in 1972, it was expected that demand would increase around sevenfold up to 2000 and that half of this would be met by new nuclear capacity (TK, 1972: 2). In 1975, after the first oil crisis, the prognosis was adjusted to a fourfold increase (TK, 1975). In reality, capacity just more than doubled from 1970 to 2000 (EnergieNed, 2001).

[7] The report of the Club of Rome in 1972 worked as a catalyst for increasing concerns over the environmental effects of industrial growth. Already in his 1970 annual speech for the Association of Directors of Electricity Companies, Chairman De Roy van Zuydewijn signalled an explosive increase in attention for environmental issues, and later that year he was confronted with extensive media attention when an oil storage tank collapsed and spilled oil in the river (Bläsing, 1992: 336-343).

where to construct new and larger power plants based on relatively cheap gas[8] with higher efficiency that enabled stable electricity prices, energy companies were forced to think about improving efficiency and energy saving under volatile price conditions and slowing demand. Securing energy supply through resource diversification and reducing energy consumption through energy saving were the pillars under the changed energy policy in the first energy paper, which in fact was the first government attempt to develop a more comprehensive energy policy (TK, 1974). Initially, decentral cogeneration was not on the agendas of electricity companies and government but the focus was foremost on central cogeneration with district heating[9]. This changed when the energy council, founded in response to the first energy crisis, pointed out the potential of industrial cogeneration for energy saving and proposed a range of measures to realise this potential[10] (AER, 1978). The council had heterogeneous membership with representatives from industry, civil society, science and the electricity sector and was less biased to the existing configuration dominated by monopolistic behaviour of electricity companies. A specific committee on industrial cogeneration was formed by the Ministry of Economic Affairs to assess impediments for industrial cogeneration more in detail and to develop recommendations to overcome these obstacles (EZ, 1980).

Mobilisation of actors for alternative routes

The second oil crisis accelerated policy change in favour of decentral cogeneration due to skyrocketing energy prices. Energy saving was central to the second white paper on energy policy and significant contributions were planned by central cogeneration through district heating, and by decentral industrial cogeneration (TK, 1979). Policy change both involved

8 After discovery of the large Slochteren gas field in 1959 in the North of the Netherlands gas was offered at relatively advantageous prices. This policy changed to a prudent use of gas after the oil crisis. In the first energy paper of 1974 also a link of the gas price to the oil price was announced, and no new gas contracts for electricity generation were settled, except for highly efficient plants, such as combined cycles of gas and steam turbines (CCGT) (TK, 1974; Bläsing, 1992; Vlijm, 2002). For example, in 1976 the Donge CCGT power plant was brought into use with an efficiency of 44% (Bläsing, 1992: 331). Steam turbines reached efficiencies of 35 to 40% (VDEN, 1980; SEP, 1994; Hofman and Marquart, 2001).

9 A committee was set-up in 1975 to investigate the potential of district heating. Although the SEP was initially sceptical regarding the economics of district heating, in light of energy saving targets, government pressure, and growing insights regarding the potential, from 1977 on 16 large scale district heating projects were initiated. The focus on larger scale was expected to improve the cost picture.

10 Relevant to note is that two decades earlier the high efficiency of decentral cogeneration relative to central generation was already reported but largely ignored by the electricity sector and government (Buiter and Hesselmans, 1999; Verbong et al., 2001).

and was triggered by changes in the networks of decision making for energy policy. One element of network change was the much stronger representation of self-producing industries in electricity affairs, such as through the industrial association[11] for power generation and cogeneration, Vereniging Krachtwerktuigen (VKW) and the cooperation between large industrial users of gas and electricity (SIGE) (Buiter and Hesselmans, 1999). A second element was the more pronounced role of civil society, and the environmental movement in particular, in shaping the electricity system. Representatives from the environmental movement took place in energy policy committees, such as the general energy council and the national steering group for energy research. Also important was the role of the 'Rethink Energy Policy Group' that was initiated in 1974 and already had informal meetings with government prior to the First White Paper on Energy[12]. This group opted for postponing the decision in favour of nuclear power plants and opted for more careful consideration of alternatives, among others by building competences for and knowledge about those alternatives. In combination with the more antagonistic approaches of the anti-nuclear energy movement that had gained strength within civil society in the course of the seventies this opened up discussion over alternative routes in the electricity system and culminated in a broad societal discussion on nuclear energy at the beginning of the eighties. An alternative scenario[13] in response to the proposed construction of three nuclear power plants by government and the electricity sector became part of the discussion. Instead of focussing on large scale, centralised power plants such as with nuclear and coal power, the focus was particularly on energy saving, cogeneration and renewable energy development within a much more decentralised energy system (Potma, 1979; Dammers, 2000). A third element was the role of industry, where increasingly attention was asked for the relative high electricity prices

[11] A specific steering group for cogeneration was set up within VKW in 1980. Members of the board were representatives of Philips, CSM, Papierfabriek de Hoop, Bos BV, Smilde Holding BV, Unilever, Shell Refinery Pernis, and Heineken. Membership increased from 80 members in 1982 to 100 in 1984 (Buiter and Hesselmans, 1999: 132).

[12] This 'Bezinningsgroep Energiebeleid' was initiated by Tuininga, who worked at TNO at that moment and been one of the translators of the Report of the Club of Rome, and was asked by his fellow party member Trip, at that moment Minister of Science Policy, to organise the science community for a rethinking of energy policy. Members of the rethink energy policy group (Tuininga, Daey Ouwens, Turkenburg, Eisma, Riedijk) had an informal meeting with Ministers Lubbers (Economic Affairs) and Trip in july 1974 prior to the publication of the first White Paper on Energy (Verbong et al 2001: 65; and personal communication with Prof. E-J. Tuininga, June 2005).

[13] This alternative scenario was developed by ir. Th. Potma, who was member of the 'Rethink Energy Policy Group' and had founded the Center for Energy Saving in 1978. Previously he worked at the Ministry of Health and Environment (Verbong et al., 2001: 80).

in the Netherlands and the disadvantageous position of industrial electricity generators with regard to delivering electricity to the grid. Concrete results were the covenant between industry and the electricity sector regarding the tariffs for connection of industrial producers to the grid, and a restitution by the Ministry of Economic Affairs compensating additional energy costs inflicted on industry due to higher prices relative to neighbouring countries (VKW, 1979; Buiter and Hesselmans, 1999: 126, 130, 140). Two further developments were crucial for the uptake of cogeneration. The gas turbine became an efficient and flexible device for electricity generation after the Second World War (Islas, 1999). With increasing concern over efficiency and the growing importance of energy saving the uptake of the gas turbine enabled increases in overall efficiency and reliability of the electricity system, by adopting it first as a device for peak generation, and later through hybridisation with the steam turbine. The gas turbine was also an attractive technology for Dutch process industry due to its high efficiency at lower scales for the combined utilisation of electricity and steam for process purposes. In the Netherlands the first gas turbines were installed in the chemical industry in 1968, at the same time when gas turbines were installed by some energy companies (Verbong, 2000: 230). The second development facilitating utilisation of the gas turbine and cogeneration was the availability of Dutch gas and its extensive infrastructure.

Attention for cogeneration was triggered by a number of reinforcing factors. Foremost, the two oil crises turned attention towards potential for energy saving and towards alternative forms of electricity generation. Secondly, from the seventies on there is a continuous reduction in legitimacy and credibility of nuclear energy as the dominant future form of electricity generation. Thirdly, the role of high energy prices, especially after the second oil crisis, in combination with high energy intensity led Dutch industry to adopt a promising emerging technology, the gas turbine, for cogeneration purposes. And fourthly, the oil crisis, environmental and nuclear concerns led to the mobilisation of actors with alternative visions regarding the way the electricity system should evolve. The resulting fundamental patterns of institutional change became especially visible in the early eighties during the broad societal discussion on the future of the energy system and the position of nuclear energy. Four main issues were discussed[14], challenging existing principles of the electricity system, and

[14] Issue one was further development of nuclear energy or not. Issue two involved a focus on energy saving or facilitating growth of energy consumption. Issue three questioned a further centralisation of the system or the uptake of decentralised alternatives. Issue four focussed on allowing for private parties for the production and sale of electricity, implying corrosion of monopolistic organisation of the sector (SMDE, 1983).

signalling significant corrosion of the legitimacy and credibility of the dominant technological and organisational form in the electricity system.

Table 5.1 Overview of main policy (P), electricity sector (E), and other (O) milestones regarding energy saving, cogeneration, and climate policy (1972-1983)

Year	Milestones
1972	White Paper on Nuclear Energy prognoses 35000 MWe nuclear power capacity in 2000 on total of 70000 MWe (P)
	Dutch publication of Club of Rome report (O)
1973	Introduction of Kalkar-levy (P)
	First oil crisis (O)
1974	'Rethink Energy Policy Group' initiated (O)
	First White Paper on Energy (P)
1975	Commission installed for advice on district heating (P)
1976	Various councils installed for energy research and energy policy (P)
	Electricity optimisation realised by Southern production companies (E)
	Final decision postponed on construction of nuclear power plants (P)
	Reactor Centre Netherlands (RCN) renamed to Energy Centre Netherlands (ECN) (P)
1977	General energy council (AER) presents advice on energy saving in companies with strong focus on cogeneration (P)
	Policy note on intensification of energy saving, three new subsidies announced (P)
	Report of committee for district heating (P)
1978	Commission installed for concentration of utilities (CoCoNut) (P)
	Center for Energy Saving initiated (O)
	Subsidy scheme for industrial investment in energy saving (P)
1979	Second white paper on energy policy: energy efficiency improvement targets set: 10% for 1979-1985 and 40% for 1973-2000 (P)
	Covenant between electricity sector and self producers regarding connection to the grid (E)
	First district heating projects initiated (E)
	First World Climate Conference in Geneva puts CO_2 problem on political agendas (P)
	Second oil crisis leads to steep increases in oil prices (O)
1980	Commission installed to investigate impediments for industrial cogeneration (P)
	Report of commission coconut (P)
1982	Follow-up report from 1980 commission as industrial cogeneration stalls (P)
	National energy optimisation realised (LEO) by the power producers (E)
	Investment subsidy for cogeneration increased from 10 to 20% (P)
1983	Final Report of the Broad Societal Energy Discussion (P/O)

In overview, a number of processes of change unfolded in the course of the seventies that effectively disrupted existing institutional logics in the electricity sector. (1) Traditional objectives of long-term security of supply and facilitating expansion to fuel economic growth were complemented by a focus on energy saving, resource diversification and environmental issues. (2) The existing actor constellation and power relationships changed as government aimed to increase central control of the system, a process of reorganisation went underway in the production and distribution sector and the SEP increased its influence at the expense of the distribution sector (Vlijm, 2002: 74). (3) The unquestioned acceptance of the electricity system as a natural monopoly ended as societal and industrial actor groups argued that expanding room for private producers would increase overall efficiency of the system. (4) The emergence of the gas turbine as a more flexible means of production disrupted the logic of increasing scales of power plants. Finally (5), mind-sets regarding the electricity system were altering as a shift was set in motion from a single focus on electricity generation to a focus on the combined provision of electricity and heat.

If we contemplate the various dimensions of sociotechnical configuration for electricity supply and use, change processes in all dimensions can be observed during the seventies although this did not yet materialise in a significant uptake of decentral cogeneration. The nature of embeddedness of the electricity system in society changed radically. Change processes were set in motion through which basic assumptions were not taken for granted anymore, basic rules were in the electricity system were re-negotiated and modified, information and communication flows regarding alternative practices were sharply increasing, new linkages were emerging involving new technologies and actor groups, new R&D directions were introduced, an more integral energy policy was initiated, and some structural changes were initiated such as allowing and supporting cogeneration as part of industrial policy separate from the electricity sector, and increasing heterogeneous compositions of advice and steering groups regarding energy policy and R&D. Table 5.2 summarises some of the main changes in the linkages of different societal fields towards the electricity system. Three levels are defined: the macro-level of modes of organisation and coordination in different societal fields, the meso-level of formation of networks and specific linkages and interactions; and the micro-level of changing routines and the development of new practices. The table shows how a range of change processes were set in motion, triggered by the combination of oil crises, environmental concerns, and societal activism and organisation.

Table 5.2 Main changes *in linkages of electricity system to societal fields (1972-83)*

	Knowledge	Politics	Economy	Society
Macro	Transformation of energy innovation system: new steering organisations emerge; new R&D directions complement nuclear energy with range of alternatives	Shift in orientation towards energy saving; emergence of integral energy policy; government aims to increase control on electricity sector;	Stronger and more organised voice of industry to allow for self-production; increasing role in energy policy and R&D directions	Process of democratisation; wave of environmental concern (media attention) and nuclear protest; higher level of organisation of environmental groups
Meso	Changing linkages in the energy knowledge infrastructure; increasing mobilisation and organisation of actors for routes alternative to nuclear energy	Changing linkages between politics and civil society; informal networks between policy-makers and societal groups	Adaptation to changing setting and demands; re-negotiation of grid connection rules	Built up of expertise, information and communication flows regarding alternatives to the existing system, formation of energy related interest and action groups
Micro	Emergence of energy (system) research centers; increase of researchers focussing on alternative routes	Built up of competences regarding alternatives, changes in routines regarding energy policy making and energy technology policy	Companies increase orientation towards energy issues and costs; gas turbines installed in some industries	Interest groups emerge focusing on energy issues with varying strategies; increased understanding of nature of environmental and energy problems

5.5 Chain reaction: understanding the fast rise of cogeneration

Expansion of the knowledge base

In the early eighties the knowledge base for cogeneration slowly expanded. Companies with processes that demand continuous steam and electricity became more and more aware of the opportunities of cogeneration with gas turbines and combined cycles, for example in 1980 VKW conducted twenty studies regarding the feasibility of cogeneration in various companies and industrial branches[15] (Buiter and Hesselmans, 1999: 133). This was also the year that the first small-scale industrial gas turbine (3.2 MW) came into operation for continuous use. VKW conducted sector studies for the paper and textiles industries and organized around ten regional meetings on energy saving and energy management, with average participation of forty businesses (Buiter and Hesselmans, 1999: 133). Furthermore, a large amount of research reports, feasibility studies, evaluations, and market research studies regarding cogeneration for a wide range of applications are published in the first half of the eighties[16]. The potential of cogeneration as an alternative to nuclear and coal-fired power plants was also prominent in the broad societal discussion in the early eighties (SMDE, 1983). In a reaction to the outcomes of the discussion, the AER pointed at the potential of cogeneration, but also at institutional constraints such as connection conditions and financial regulations in the electricity sector, and at disappointing growth figures relative to expectations (AER, 1984). See also Table 5.3 for an overview of main policy documents and other developments impacting the course of cogeneration in the period 1985-1997.

Uptake of cogeneration in process industries

In the first half of the eighties investments in decentral cogeneration slowly started to pick up, mainly because investments were undertaken in a range of process industries whereas in the period of 1968 until 1978 virtually all investments in cogeneration took place in the chemical industry where cogeneration capacity expanded from 300 to 830 MW during that period (Blok, 1991: 132). In terms of actual investment several cogeneration units were installed in the period 1980-1985 in refineries, the paper industry, the food industry, and the chemical industry, with overall annual investments ranging from 40 to 110 MW (Blok, 1991: 134). Relevant economic factors for the uptake were improved electricity tariffs for cogeneration due to the 1979 negotiated agreement between self-producing industries and the electricity sector, and subsidies on investment in energy saving that also applied for cogeneration initiated in 1977. Investment grants were increased from 10 to 20% in 1982 after advice in the second report of the committee on industrial cogeneration and the General Energy Council (EZ, 1982; AER,

15 In previous years Potma had also pointed out the lack of knowledge regarding cogeneration in government circles and the dominant orientation towards centralised large-scale power plants (Potma, 1979).

16 See for example the references in the advice on cogeneration by AER (1987), the work by VKW and a range of studies undertaken by the Centre for Energy Saving. While the studies originate from different segments of the electricity sector, government, and industry, the prominent roles of VKW and the Centre for Energy Saving (initiated by Potma, author of the forgotten scenario) stand out.

1982; Blok, 1991; Buiter and Hesselmans, 1999: 132). Both Van der Doelen (1989: 262) and Blok (1991: 154) find a significant but small positive effect of these grants on investment behaviour of industries. The advisory committee had also quantified a cogeneration target of 2000 MW installed capacity in the year 2000 and gave recommendations on several issues, among others, the type of fuel base (at first coal and synthesized gases because of restrictions on gas sales, but later natural gas as preferred choice), the type of technology, the tariff-structure for electricity deliverance to the national grid, the so-called wheeling of cogenerated power among private corporations and policy measures to support CHP investments.

Table 5.3 Overview of main milestones regarding energy saving, cogeneration, climate policy, and the electricity sector (1985-1997)

Year	**Milestones: policy (P), electricity sector (E) and other (O) developments**
1985	EU formulates energy objectives for 1995 (P)
	Report by commission regarding reorganisation of the distribution sector (E)
	Policy Note on Electricity Supply in the Nineties: decision to allow expansion of nuclear energy ao taking into account the results of the Broad Societal Discussin (P)
1986	Draft electricity act submitted in parliament (P)
	Sixteen electricity producers bundled in four regional production companies (E)
	Nuclear accident in Tsjernobyl (O)
	Government decides to suspend expansion of nuclear energy (P)
1987	AER advice on cogeneration
	Brundtland commission publishes Our Common Future (WCED, 1987) (O)
	Policy stimulation program for cogeneration (P)
1988	EU report on internal energy market (P)
	RIVM publishes 'Zorgen voor Morgen' with a worrisome picture of the environmental state (O/P)
1989	Electricity Act 1989 (P)
	First National Environmental Policy Plan: specific energy efficiency and CO_2 reduction targets per target group (P)
	Distribution sector installs steering group for integral environmental policy plan (E)
1990	Second World Climate Conference in Geneva with EC countries reaching agreement on stabilisation target for CO_2 for 2000 relative to 1990 (O/P)
	National Environmental Policy Plan Plus sharpens CO_2 reduction targets (P)
	Gasunie introduces special gas tariffs for cogeneration (O/P)
	First White Paper on Energy Saving: Energy efficiency itarget of 20% improvement for 1989-2000, effectively 2% annual (P)
1991	First White Paper on Climate Change Ministry of Economic of Affairs signs set of agreements regarding energy saving with distribution sector (P)
	First overall environmental action plan (MAP) of the distribution sector published, and MAP-levy introduced (E)
	EnergieNed founded as association for distribution companies, through a fusion of VEEN (energy distributors), VEGIN (gas), and VESTIN (heat) (E)
1992	UNCED conference in Rio de Janeiro develops Agenda 21; Climate treaty is signed (O/P)

1993	Second National Environmental Policy Plan (P)
	Second White Paper on Energy Saving: Energy efficiency improvement target reduced to 17% for 1989-2000, effectively 1.7% annual
	Nine distribution companies and one producer publish vision in Horizon 2000 with liberalisation as central tenet (E)
	Four producers, EnergieNed, GasUnie and Sep publish vision Together with own Identities with return to the pre-1989 situation of integrated electricity companies as central tenet (E)
1994	Sharp reduction of public budgets for cogeneration announced by new government (P)
	Moratorium agreed for decentral cogeneration between distributors (EnergieNed) and producers (SEP) (E)
	Second Environmental Action Plan of the distribution sector, with increased targets for CO_2 reduction (E)
1995	Third White Paper on Energy Policy: target of energy efficiency improvement of 33% for 1995-2020, effectively 1.6% annually. Cogeneration capacity targeted to rise to 8000 MWe in 2000 and 14000 MWe in 2020 (P)
	Subsidies for cogeneration replaced by fiscal measures (investments become tax deductable) (P)
1996	Introduction of Regulatory Energy Tax (P)
	Policy note streamlining towards an electricity market (P)
	EU directive on common rules for the electricity market (P)
	Second White Paper on Climate Change (P)
1997	Kyoto-protocol agreed at World Climate Conference with a CO_2 reduction target of 5% for 2000-2010 for developed countries (P)
	Energy Distribution Act (E)
	Third Environmental Action Plan (1997-2000) of the distribution sector (E)
	SEP closes down Dodewaard nuclear power plant (E)

A stimulation package for cogeneration is unfolded

Despite these efforts, the growth of cogeneration during 1980-1985 was below expectations and at the end of 1986 a motion was formulated in parliament to formulate a stimulation program (AER, 1987). Important factors triggering renewed discussion on cogeneration in that year were the drop in energy prices that had slowed down energy efficiency improvements and the Tsjernobyl accident in April 1986 that effectively closed the nuclear route for electricity generation. In a follow-up, the AER concluded that much of the potential for cogeneration was not being realised. In their advice, the AER therefore proposed in the first place to let the lower gas tariffs for large users also be applicable for smaller cogeneration units. After negotiation with Gasunie and VEGIN[17] this advice was almost immediately followed (AER, 1987: 8-9). The second issue involved remuneration tariffs for electricity that were still considered low. The AER argued for an increase in remuneration tariffs to be part of the then ongoing negotiations between SIGE, VKW and the association of energy distributors, VEEN (AER, 1987:

[17] Association of gas companies in the Netherlands.

10-12). The third issue involved the role of energy distributors. The AER argued that the realisation of the potential of cogeneration can be considerably improved with a more active role of distribution companies, for example through establishing joint ventures with the private sector in which risk and benefits of cogeneration can be distributed over the two parties. This could facilitate cogeneration units dimensioned on heat demand instead of electricity demand, which would increase the potential for cogeneration and energy saving. The AER also argued that the reorganisation of the distribution sector and the separation between electricity production and distribution could be an incentive for competition based on cogeneration by the distribution sector relative to the production sector, as was proposed in the draft 1987 electricity act (AER, 1987: 12-13). Also the advisory committee for industrial cogeneration pointed at the potential role of distribution companies, for example in the form of setting up joint-ventures with industry as this could induce the set up of cogeneration units dimensioned on heat demand and would realise more re-delivery of electricity to the grid (EZ, 1987).

Based on the recommendations of general energy council and the advisory committee for industrial cogeneration, the Ministry for Economic Affairs initiated a stimulation program for cogeneration. The program included measures such as an increase of the investment grant to 25% (Blok, 1991: 144) and rules regarding the special tariff for natural gas for cogeneration (especially attractive for smaller units). The remuneration system also changed in anticipation of the vertical disintegration of production and distribution companies, under way at that time. The new system remunerated all deliveries to the grid by a tariff based on avoided fuel costs and saved capacity costs (Arentsen, Hofman, Marquart, 2000: 28). Finally, the program introduced a special project office for the promotion and support of cogeneration, set up in 1988 to function as a broker in the realisation of cogeneration projects and to stimulate cooperation between utilities and the private sector, such as in the form of joint-ventures (Blok, 1991: 143).

A new setting for cogeneration: Policy change and a new role for energy distributors

Two factors drastically changed the climate for cogeneration at the end of the eighties. The first factor was the effect of the reorganisation of the electricity sector on strategies of energy distributors. The second factor was the emergence of environmental policy oriented at target groups, with the energy sector as one of the target groups, under the first national environmental policy plan. The process of concentration in the electricity sector[18] and the unbundling of power production from distribution led to a reorientation in the distribution sector. The dominant role of the SEP in the proposed electricity act and the dominance of the four production units in SEP, made the distributors increasingly feel submitted to the SEP and fuelled a strategy of strengthening their position through mergers[19] and clustering of interests (Arentsen et al., 1997; Köper, 2003: 48-52). In the new structure, efficiency by central production by SEP was among others to be driven through competition with decentral production by distribution utilities and private companies. In the Electricity Act of 1989 electricity distributors were allowed to install decentral production facilities of up to 25 MW, whereas industry was allowed production facilities up to 400 MW. A new tariff structure was introduced with a national base tariff set by producers that formed the basis for somewhat diverging regional base tariffs to which individual costs of utilities could be added to a certain maximum. Central producers were moreover obliged to contract decentral produced electricity against avoided costs. The distribution sector took this opportunity to develop decentral generation and utilised cogeneration as the main option also to strengthen its position in the power struggle against the producers[20]. In essence, the restructuring of the electricity sector triggered a process of divergence in the positions between producers and distributors as the distributing companies started to develop a much stronger orientation towards the market relative to the supply orientation of producers. Vlijm (2002) describes how this changeover from a task orientation towards a client orientation required changes at all levels of organisation in a regional electricity distributor. Secondly, this strategy coincided with the emergence of the national environmental policy plan which selected the energy sector as one of the target groups where reduction in a range of emissions was to be realised, with energy saving, climate change and CO_2 reduction as prominent issues (VROM, 1989, 1990). This change in environmental policy was part of a new wave of environmental consciousness and environmental policy from the second half of the eighties where a more integrated approach

[18] The number of production companies was reduced from fifteen to four in 1986. Reduction of the number of distributors took longer and also involved horizontal integration of distribution of gas, electricity, water.

[19] The process of concentration in the distribution sector was also driven by pressures of national government, who threatened to formalise an electricity distribution act with minimum amount of connections for distribution companies if the sector did not significantly reduce the number of companies (Vlijm, 2002; Köper, 2003).

[20] Based on personal communication with ir. W.K. Wiechers, former chairman of PNEM and Essent, April 2005; Vlijm (2002); and Köper (2003). During the course of the nineties, in anticipation of Eropean energy markets, the focus was on further restructuring of the production sector towards one large scale production company. The distribution sector was very wary of these plans as they threatened to further undermine their position.

replaced the focus on a compartmental division of problems and solutions, which had foremost implied end-of-pipe technologies for emissions to water, air and soil (Hajer, 1995; Mol, 1995). In order to reach the targets set with regard to energy saving and CO_2 reduction, representatives of the Ministries of Environmental Affairs and Economic Affairs at that time were convinced of the importance of an intermediary actor, or implementation agency, to reach and convince households, industries and other actors where energy saving measures had to take place. The electricity distributors were an obvious candidate although the Ministry also contemplated other options, such as initiating alternative energy saving utilities. Discussions between energy distributors and the Ministry took place during the preparation of the first National Environmental Policy Plan (Dinkelman, 1995: 122; Ligteringen, 1999). The distribution sector began to see opportunities of a shift of strategy into a more environment friendly direction and started to develop ideas, one of which was levying a surcharge to consumers that could be used to finance investments in energy saving measures under the umbrella of an environmental action plan (Ligteringen, 1999: 145). This idea was further developed by the director of the association of energy distributors, VEEN, and a steering group was set up to develop action plans for the sector, later followed by individual environmental action plans by energy distribution companies[21]. Support for the steering group was given by consultancy McKinsey and their associate Winsemius, who had been responsible as Minister of Environmental Affairs for the birth of the target-group and theme oriented approach of the national environmental policy plan (Hajer, 1995; De Jongh, 1999), played an important role as consultant in the process[22]. In the first overall environmental action plan of the sector in 1991, based on individual action plans of 52 distribution companies, a CO_2-reduction target for 11% was set for 2000 to be realised by a set of measures, with cogeneration as a dominant option due to its relative high cost-effectiveness and its large impact on CO_2 emissions. Also a set of agreements was concluded with the Ministry of Economic Affairs, such as the funding of the environmental action plans through a so-called MAP-levy on electricity (Dinkelman, 1995: 225-226).

Breakthrough in cogeneration as change processes interlocked

An unprecedented boom in decentral cogeneration occurred in the nineties as its share in domestic electricity generation rose from 15 to 36% (see figure 5.3) and decentral cogeneration capacity increased with 3500 MW from

21 The idea for an environmental action plan was also discussed with environmentral groups, such as the Bezinningsgroep Energiebeleid in february 1990 (Dinkelman, 1995: 260).

22 Personal communication with ir. W.K.Wiechers, former chairman of PNEM and Essent, April 2005.

1989 to 1999. In one decade the face of the Dutch electricity system radically altered as also imports increased fourfold. The steep increase in cogeneration can be understood as the interlocking of several change processes that created strong momentum for cogeneration. Restructuring in the distribution sector, its increasingly subordinate position relative to the producers, and the market orientation it developed, led distributors to use cogeneration as a means to compete with the production companies. The search for a new role and identity also led the sector to see contribution to the national environmental policy plan as a way to broaden its task and to strengthen its client (and societal) orientation[23]. Cogeneration thus fulfilled a triple role: strengthening its relation with clients, strengthening its position relative to the central producers, and improving its environmental profile. Preparedness for change in the distribution sector thus coincided with a change in policy that stimulated target groups to actively commit to environmental goals. The new rules laid down in the electricity act also supported development of decentral cogeneration as purchase of the produced electricity was obligatory against a fixed tariff scheme.

Cogeneration expanded to various sectors facilitated by changing organisational forms

Production of electricity based on decentral cogeneration increased sharply from 1990 on, carried by increases in a range of industries, horticulture and service sectors such as health care and recreation. This is indicated by table 5.4 where also the importance of the emergence of cogeneration units under control of distributors is indicated. The active role of distribution companies in bringing cogeneration to the market led to a wave of projects in sectors where the number of cogeneration units previously had been limited. The heterogeneous character of industry and horticulture demanded a tailor-made approach, and the distribution sector had to built up knowledge and experience for which they worked together with Novem[24] and national branch associations (EnergieNed, 1994). For example for horticulture and health care plans of action were developed in collaboration with the project office for cogeneration[25] and total installed small-scale capacity increased

[23] This is illustrated by a policy note of the electricity distributor PGEM in 1989 in which three core elements were developed: client orientation, care for the environment, and decentral generation (Vlijm, 2002: 196). The new policy led to expansion of decentral generation capacity of PGEM from approximately 70 MW in 1989 to 336 MW in 1994 (Vlijm, 2002: 190-191).

[24] The implementation agency of the Ministry of Economic Affairs for various energy saving and R&D programs.

[25] This project office was jointly financed by the electricity sector (SEP and EnergieNed), Gasunie, and the Ministry of Economic Affairs. In 1998 funding was ended and the project

from 220 MWe in 1990 to just over 1500 MWe in 2000[26] (Boonekamp et al., 2002: 35). The project office also gave information to companies regarding optimal scales, technologies, and organisational forms regarding cogeneration[27] (PW/K, 1990, 1995; Cogen, 1997, 1998). Also the existing engineering consultancy infrastructure played an important role in the spread of cogeneration units. In horticulture and health care the cogeneration installations were smaller scale units, up to 1 MWe, based on gas engines. Distribution companies also increasingly established joint-ventures with industries, in order to be able to develop larger scale cogeneration units and to circumvent the maximum allowed unit scale of 25 MWe under the 1989 Electricity Act[28]. Moreover with the fixed re-delivery prices for electricity from cogeneration, units increasingly were dimensioned on local heat demand, selling excess electricity to the grid. The attitude of industry towards cogeneration was also positively influenced by the long term agreements on energy efficiency that were signed from 1993 on by a range of industrial branches and other sectors with the Ministry of Economic Affairs, with for example horticulture as one of the first entering into a long-term agreement. The voluntary agreements signed with industrial sectors on energy efficiency improvement all stressed the potential of cogeneration to achieve the agreed efficiency improvements. Energy distributors used the supportive climate to further develop decentral cogeneration and used the electricity of auto-producers as a cost-effective means in peak-management. Distributors developed cogeneration activities in two directions. In smaller projects up to 1500 kWe, distributors took the risk of investments and bought electricity surpluses to deliver to the grid. In the larger projects, predominantly with industry, risks and profits were shared by establishing joint ventures, providing advantages for both parties (Arentsen, Hofman, Marquart, 2000: 44).

office was divided into the consultancy Cogen projects and the Foundation COGEN Nederland which represents interests of business members regarding cogeneration.

[26] There was a total estimated number of 3500 gas engines in 2002 (Van Dijk, 2004: 77).

[27] For example in 1990 a workshop was organised regarding various collaborative forms for cogeneration, with a strong focus on joint-ventures (PW/K, 1990).

[28] Such as the Elsta power plant in Terneuzen with 475 MWe capacity. This was a joint-venture between the chemical firm Dow, and energy distributors Delta and Essent.

Table 5.4: Total decentral cogeneration by sector (GWh)

	Waste incine-ration	Energy distri-butors	Food industry	Paper industry	Chemical industry	Other ind.	Horti-culture	Health-care	Other	Total
1990	2618	192	1190	1261	5534	387	327	142	593	12244
1991	2890	378	1166	1285	5735	381	389	169	294	12687
1992	3096	674	1405	1289	6130	391	550	182	331	14048
1993	3374	1595	1341	1363	6522	377	686	187	386	15831
1994	3356	2342	1554	1477	7328	366	802	232	364	17821
1995	3492	2802	1860	2127	8027	382	1014	279	380	20363
1996	4064	4203	2677	2490	8341	481	1580	486	673	24995
1997	4809	4753	2624	2542	8502	555	1666	525	719	26695

Source: Central Agency for Statistics, The Dutch energy economy, 1990 - 1998, 1991 – 1999.

Expansion of cogeneration created over capacity in the electricity system

The increase in cogeneration and its preference over central generation (due to the obligation to purchase against fixed feed-in tariffs in the Electricity Act) led to a deteriorating market position of the central producers. The decrease in their market share forced producers to increase supply tariffs for distributors, but in the fixed tariff structure this also triggered higher remuneration tariffs for cogeneration. This tariff structure locked-in investments in cogeneration and accelerated their expansion. Every increase in cogeneration decreased the market share of central production, consequently increasing the remuneration tariffs for decentral production, further increasing attractiveness of investments in decentral cogeneration (ECN, 1995; Vlijm, 2002; Köper, 2003: 52). The increase in cogeneration contributed to over capacity in the Dutch electricity system and attacked the system of central electricity planning by the SEP. Therefore, the SEP initiated a moratorium on investments in cogeneration in 1994. SEP and EnergieNed agreed to postpone or to cancel[29] about 460 MW planned decentral cogeneration capacity, financially compensated by SEP (40 mln. Euro). Industry strongly opposed the moratorium as they argued that ineffective planning of SEP had caused over capacity. Their viewpoint was that cogeneration contributed to the attainment of national environmental goals and SEP had not anticipated these advantages in its electricity planning[30]. SEP, however, refused responsibility for over capacity because it could only count for ***real*** installed decentral installed capacity, and not for ***planned*** decentral capacity in the biannual electricity forecasts of demand

[29] The total reduction of planned capacity was estimated to amount 1.100 MW in the years to follow (Press release SEP / EnergieNed 27-01-1995)

[30] Environmental goals not feasible without cogeneration (In Dutch), *NCI: orgaan van de Vereniging van de Nederlandse Chemische Industrie,* 1994, vol. 22: 4-5

and supply. Only after they were offered financial compensation, industry accepted the moratorium. Due to the moratorium, Dutch distributors were able to negotiate a new (better) supply contract with SEP, the so-called protocol. This new contract, which ran from 1996 until 2001, however, also included restrictions on decentral cogeneration initiatives of distributors. The rate of investments in cogeneration by distributors slowed down, also because of changes in the financial support system for cogeneration. The reason for this change of policy was its success: decentral cogeneration capacity had steeply increased and therefore the financial support could be terminated (TK, 1995: 107). Finally, in the aftermath of the moratorium, remuneration tariffs decreased. Despite these discouraging measures, the impact of the moratorium was rather restricted. After 1994, investments in decentral cogeneration capacity continued, and only slowed down after the introduction of liberalization in 1998.

If we contemplate the various dimensions of sociotechnical configuration for electricity supply and use, we argue that the alignment of a number of change processes fuelled an unprecedented boom in decentral cogeneration. Table 5.5 provides an overview of main patterns of change at the structural, macro-level, meso-level of network formation and emerging institutional arrangements and micro-level of actors, their routines and competences. Adoption of energy saving targets by distributors and industry were initiated by policy change towards target groups and intermediary organisations for implementation. The reorganisation in the electricity sector led distributors to engage in cogeneration as a means in the power struggle versus the producers, while a network of intermediaries were able to provide standardised information packages to typical industries and tailorised solutions to individual companies. In combination with the emerging match of cogeneration to the joint-venture as organisational form this reduced risks and transaction costs for industries, and led to a distribution of risks and benefits over distributors, industries and knowledge brokers.

Table 5.5 Main changes in linkages of electricity system to societal fields (1985-97)

	Knowledge	Politics	Economy	Society
Macro	Knowledge organisation is modified as specific knowledge broker organisations emerge	Policy change towards integrated approach for target groups; orientation on long-term targets energy saving priority is combined with focus on CO_2 reduction; Electricity Act unbundles production and distribution	Reorganisation of electricity sector; Strong orientation of distributors to industry; industry adopts energy saving targets	New wave of environmental concern; professionalisati on of ngo's
Meso	Knowledge brokers work towards standardisation of cogeneration and tailorisation for specific groups	Focus on implementation with target groups; inclusion of ngo's in the process; orientation on long-term targets; focus on intermediairies to spread new practices	Reorganisation distribution sector; new collective strategy developed; Networks between industries, intermediairies and distrbutors are formed	Alignment of ngo's towards environmental policy making
Micro	Increasing competences are developed regarding system design aspects of cogeneration; expansion of research on energy management	Routines change towards more interaction with target groups in formation and implementation of energy policy	Change processes towards more client orientation; built up of new competences; emergence of new routine; joint ventures as emerging organisational form; uptake of energy saving in industries	Ngo's take role to monitor and account for energy saving

5.6 Backwash: understanding stagnation in cogeneration

Stagnation in cogeneration capacity and production

The sharp increase in capacity and production of cogeneration abruptly stopped after 1999. Capacity fell slightly in the period until 2003 and production based on cogeneration dropped more significantly, leading to a fall of the cogeneration share in domestic electricity generation from 36% to 31%. Changes in rules for cogeneration and deteriorating market conditions were important factors. Major changes in regulation of the electricity sector occurred which also affected remuneration and other tariffs. Table 5.3

provides an overview of major policy milestones and other developments affecting the course of cogeneration in the period 1998-2005.

Basic rules for cogeneration change with the introduction of the 1998 Electricity Act

The 1998 Electricity Act significantly changed the national regulation of the electricity system. Restrictions on power generation disappeared and electricity trade and supply adopted the competitive model. The changes also ended the special position of decentral cogeneration in the Dutch electricity system. The application of preferential gas prices for cogeneration was terminated. Remuneration tariffs for larger cogeneration units had to be negotiated in a competitive setting. Cogeneration capacity units of less than 2 MWe still benefited from existing remuneration schemes until 2002. Special regulations for all other cogeneration installations were ended. From 1998 on cogeneration based auto-producers were submitted to the general transmission and transport tariffs in the Dutch electricity market. These tariffs turned out to be rather disadvantageous for cogeneration, and interest organisations of auto-producers tried to change the tariff treatment of decentral cogeneration capacity, but without success[31]. The Dutch government acknowledged liberalization could harm the further penetration of cogeneration in the Netherlands, but argued that EU-regulation on fair competition no longer allowed for special treatment of cogeneration in electricity trade and supply. Instead, the government used the tariff of the energy tax to further support cogeneration (charging auto-produced electricity to satisfy own demands for half the tax tariff) and extended the fiscal support program for tax deduction of energy investments. Imports rose strongly due to the process of liberalisation of the Dutch electricity market and negatively affected competitiveness of cogeneration. In period 1989-1999 electricity prices were mainly determined by gas prices as the Dutch park of power plants utilised gas as its main resource, and changes in gas price had no major effect on profitability of cogeneration. This changed due to liberalisation as rising imports led to a much stronger influence of nuclear and coal-fired power on the electricity price, especially in off-peak periods. In combination with rising gas prices (and continuously low coal prices) this led to a deterioration of the market position of cogeneration.

[31] Tariff codes fatal for cogeneration (in Dutch), *Energietechniek,* 10 (77), 1999: 514.

Environmental action plans of distribution sector ended

The year 2000 marked the end of the environmental action plans of the distribution sector. The sector had been successful in realising the target of 17 million tonnes of CO_2 in 2000 relative to 1989 with cogeneration contributing strongly to reductions in industry (EnergieNed, 2001a). From 2000 on energy saving activities, and investments in cogeneration, are therefore being led by the demands of the market. Energy conservation has become part of the strategy of distributors to provide full service to customers, whereas some distribution companies view sustainability as one of the cornerstones of their profile and strategy. But the deteriorating market circumstances put cogeneration under pressure, and led to closing down of several units. Also the share of cogeneration under control of distributors dropped (especially for the smaller units), indicating a shift of the risks back to horticulture, service sectors and industries[32].

Table 5.3 Overview of main milestones regarding energy saving, cogeneration, climate policy, and the electricity sector (1998-2005)

Year	*Milestones: policy (P), electricity sector (E) and other (O) developments*
1998	Electricity Act 1998 (P)
	TenneT initiated as independent grid manager
	Third White Paper on Energy Saving: energy efficiency improvement target of 2.0% annual for 1998-2010
	Third National Environmental Policy Plan
1999	Free choice of electricity provider for large electricity users
	Covenant Benchmarking energy efficiency agreed between Ministry of Economic Affairs and energy intensive sectors: goal is to be among top energy efficient industries in 2012
2000	Gas Act 2000
2001	Fourth National Environmental Policy Plan
	Liberalisation of market for green electricity
	The SEP is dismantled
	Extra support measure for cogeneration announced
2002	Liberalisation of electricity market for medium-sized businesses
	Kyoto-protocol ratified by the Netherlands
	Report of Commission Vogtlander regarding carbon emission trade
2003	New support program based on environmental quality of electricity production is initiated
2004	Full liberalisation of the electricity market
2005	Kyoto protocol comes into force as Russia ratifies

[32] Personal communication with R. Harmsen, cogeneration expert of ECN Policy Studies, Amsterdam, May 2005.

Prospects for cogeneration

Dutch public authorities are not optimistic regarding the further increase of cogeneration under liberalization. The over capacity in the (European) electricity market and expected electricity price decreases are expected to worsen the national climate for investments in cogeneration. The open access to rather cheap coal and nuclear-based electricity in Europe has negatively affected the competitiveness and profitability of cogeneration. The pessimism is further fuelled by the idea of maturity of the potential of cogeneration in Dutch industry. The political goal of 15.000 MWe cogeneration in 2010 is conceived as too ambitious by a range of actors (Arentsen, Hofman, Marquart, 2000). Other actors tend to stress the strengths of cogeneration in a liberalised market (Arentsen, Hofman, Marquart, 2000):

- The flexibility of cogeneration with respect to energy supply (heating, cooling, electricity, emergency power, etc.) will pay off in the form of higher returns. The tariff structure will no longer be based on standard costs, but on the real costs of the moment;
- Remote control systems will become more important, especially for distribution companies, because it enables them to utilise decentral installed capacity to get the highest returns on their electricity production;
- Cogeneration units have a short construction time and relative short payback periods. This can be an important asset in the changing energy market of the Netherlands;
- The concept of cogeneration still offers room for the improvement of efficiency, for instance in combination with stand alone heat pumps and by adding technology (absorption coolers) to produce coldness in summertime;
- Powerful actor coalitions (Gasunie, distributors, equipment producers) have formed a coalition to develop and diffuse micro cogeneration units to the level of houses and neighbourhoods in order to safeguard and expand their market positions (sale of gas, number of connections, sale of equipment respectively).

Table 5.6 provides an overview of main patterns of change at the structural, macro-level, meso-level of network formation and emerging institutional arrangements and micro-level of actors, their routines and competences. If we contemplate the various dimensions of sociotechnical configuration for electricity supply and use the process of liberalisation of electricity markets has impacted all fields and reinforced the market orientation of cogeneration. Contracts for remuneration have to be negotiated with individual buyers, and rules for grid connection and grid transport tariffs deteriorated conditions for cogeneration, and were later renegotiated. Opening up of markets led to changes in competitive forces for cogeneration, as gas-based cogeneration electricity competed with nuclear and coal-based electricity from France and Germany.

Table 5.6 Main changes in linkages of electricity system to societal fields (1998-05)

	Knowledge	*Politics*	*Economy*	*Society*
Macro	Re-organisation of private R&D through stronger market orientation; public R&D focuses on energy system aspects	Electricity Act 1998 initiates liberalisation of electricity markets; independent grid operators emerge; renegotiations of rules for gid connection, change towards transition policy; shift towards use of market incentives	New mode of coordination between industry and electricity based on free choice of electricity; changing (and renegotiation of) rules for grid connection and remuneration; international orientation	Changing ngo orientation towards collaboration with business; information society creates changing energy demands
Meso	R&D instruments focus on collaboration; formation of transition coalitions	Changing linkages with energy companies develop; policies facilitating transition processes	Industries organise electricicy needs to negotiate contracts with electricity companies;	Ngo’s provide legitimacy for sustainable energy initiatives; information society as tool to increase transparency
Micro	Build up of competences regarding	Re-positioning and changing routines in a liberalised electiricy market	New forms of contracts emerge, new ways of settling contracts (internet, apx); coalitions for micro-cogeneration emerge	Changing routines towards collaboration with industries

5.7 Applying an institutional perspective

Four phases can be discerned in the uptake of decentral cogeneration. Each phase is characterised by typical change processes, problem-solution pairs, factors and actors involved, represented in Table 5.4. Some overall conclusions are that it is essentially a multi-faceted, multi-actor and multi-level process in which the dominant design and beliefs of the electricity system were undermined, and actors and factors became mobilised around an alternative socio-technical configuration, leading to full institutionalisation of that alternative configuration. While external factors (oil crises, energy prices, Tsjernobyl) were crucial to change the course of the existing system and to trigger alternative search processes, more intricate processes of change in the linkages between the electricity sector and the policy and economic system, were decisive for the sharp increase in cogeneration.

Table 5.4: Characterisation of the evolution of cogeneration

Phase / Aspect	(1) Awareness, public scrutiny	(2) Mobilisation of actors and alternatives	(3) Institutionalisation/ Utilisation	(4) Stabilisation
Main change processes	Corrosion of growth paradigm sector, focus on energy saving forces sector to develop district heating, public scrutiny of system rises	Increasing information flows and built up of competences for cogeneration, changing circles of decision making for policy and knowledge, modification of rules for grid connection, mobilisation of actors around cogeneration, support schemes for cogeneration	Restructuring of the electricity sector catalyses diverging strategies; policy focus towards target groups; commitment of e-sector and industries to energy saving; change of rules for grid connection and remuneration; joint-venture as organisational form	Liberalisation of the electricity sector; changeover from policy (targets) to market (incentives) as main force for integration of environmental issues and energy saving
Main problem-solution pair	Nuclear power and district heating for security of supply and energy saving	Nuclear and coal power for long-term supply of the e-sector; cogeneration for industrial sector to secure competitive energy prices as part of industrial policy	Cogeneration as major strategy for energy saving; cogeneration as means of introducing competition in e-sector to improve efficiency	Level playing field and getting the prices right (emission trading) to increase efficiency and competitive prices
Main factors	Oil crisis, societal forces, policy re-orientation, gas turbine emerges as power production option	Oil crisis/energy prices, broad societal discussion, cogeneration as feasible and reliable option, gas for cogeneration	Wave of environmental concern; Tsjernobyl; standardisation of cogeneration as energy management option, learning across range of adopter groups, strong intermediairies, good fit with organisational form	Wave of liberalisation, European electricity directive, electricity imports
Main change agents	Ngo's	Larger industries, emerging knowledge centers	Distribution companies, policy makers	European Union, electricity users, new entrants

In comparison to overall less prosperous uptake of cogeneration in other European countries those specific institutional change processes provide an explanation for these differences in uptake. This also leads to the conclusion that gas turbine development was a necessary but not sufficient condition for the uptake of decentral cogeneration. One counter argument could be that the Netherlands witnesses a gas infrastructure and gas abundance that has been conducive for the uptake of decentral cogeneration. We agree that availability of gas has facilitated the uptake of decentral cogeneration but would argue that this can not explain the nature of the institutional change processes that have occurred and were decisive for the creation of an alternative competing decentral design to the central station electricity system in the Netherlands.

A more detailed look at the evolution of decentral cogeneration leads to the following conclusions. First of all we need to stress the extent of change that had to take place in order to make the large uptake of cogeneration possible. This involved changes in routines of a range of actors, radical organisational changes within the electricity sector (from supply orientation to client orientation, and from regional monopolies to market organisation, among others), and radical policy change within the departments of environmental and economic affairs (the theme and goal oriented target group policy). It involved changes in energy management routines in several adopter groups, ranging from process industries, to horticulture, to health care organisations, swimming pools, and hotels (and supported by the long term agreements on energy efficiency in a range of sectors). It also involved the emergence of a strong set of intermediaries, who provided information about the potential (relative advantage) of cogeneration; who could relate prospective adopters to earlier adopters; who could reduce the complexity of the decision to be taken; and who could convince potential adopters regarding the feasibility and compatibility of cogeneration within their existing production and service processes[33]. And it involved the emergence of a good match between technological and organisational form (the joint-venture) that distributed risks and benefits and reduced transaction costs in a way beneficial to collaborating parties. Overall these change processes benefited from the improved cost conditions through fundamental changes in the rules applying for remuneration and grid connection and through continuous policy support schemes. Subsidies and fiscal investment measures were a necessary condition (here we agree with earlier research from a.o. Blok, 1991; 1993; Blok and Turkenburg, 1994; Beeldman, 1995; Elzenga et al., 2001) but, we

[33] Here, the categorisation of Rogers (1995: 207) of perceived attributes of innovations is applied.

add, not a sufficient condition for the sharp uptake in cogeneration in the Netherlands.

The uptake of cogeneration has transformed the Dutch electricity system and transformation of the Dutch electricity system has facilitated the uptake of cogeneration. Thus, one major conclusion is that the rise of cogeneration needs to be understood in the process of reorganisation of the electricity sector, and especially in the light of diverging (and at certain times competing) strategies in distribution and production companies. It is relevant to stress this element of competition in the light of the foremost consensus-oriented transition policy that is currently undertaken. Another conclusion is that the uptake of cogeneration is part of more broader process of societal change that in the 1970s included the end of the idea of unlimited growth for the progress of all, and involved a broader social movement against the technocratic style of decision-making, especially reflected in the discussion on nuclear energy in the 1970s where the establishment saw nuclear energy as solution to the problem, whereas groups in civil society saw it as part of the problem and advocated a different design of the electricity system. Advocates of this different design, such as the Center for Energy Saving and the Rethink Energy Policy Group[34], played a central role as they advanced these alternative ideas relative to the dominant thinking of the electricity sector and government at that time, but also because they slowly became part of the change process as they entered circles of decision making or catalysed knowledge and consultancy centers regarding these alternative routes. Processes of change are thus also people-related and dependent as also the emergence of Winsemius shows and the changes in organisation and routines he initiated in the department of Environmental Affairs.

Overall, the way the electricity system is embedded in society has fundamentally changed. The reduction of legitimacy and credibility of the central station electricity system has initially led to de-institutionalisation of its linkages to wider fields in society. Instead a more demand-oriented electricity system biased towards cogeneration gained legitimacy and was supported by institutional changes. The process of liberalisation however has set in motion diverging processes. On the one hand, a re-institutionalisation of the central station electricity system has taken place at a cross-national level as national electricity markets opened. This system is also deriving legitimacy based on high expectations for integration of large-scale renewable energy resources such as off-shore wind farms, co-combustion of coal-fired power plants with biomass (Raven, 2005), and biomass based power plants. Even the nuclear option might re-emerge in the light of the Kyoto-protocol and long-term security of supply. On the other hand

[34] In Dutch: Bezinningsgroep Energiebeleid.

liberalisation has triggered a range of new products, services and technologies, frequently in combination with the shift towards an information society, and sometimes at rather local demand-oriented scales. Here a process towards integration of even more flexible and decentralised systems is a possibility, such as micro-cogeneration at the level of households. Despite these two trends, we contend that cogeneration is rather firmly rooted and institutionalised in the current electricity system and wider fields of society. Liberalisation has ended the highly favourable climate for cogeneration, but institutions, rules and the energy saving paradigm has stabilised its position within the electricity system and wider fields of society.

Chapter 6

The institutionalisation of green electricity[1]

An example of transformation in the Dutch electricity system

6.1 Introduction

One of the most salient developments in the Dutch electricity system in recent decades has been the emergence and spread of green electricity. Both energy companies and consumers have embraced green electricity as a concept in which electricity produced by renewable energy sources is separately marketed and priced from conventionally generated electricity based on fossil or nuclear sources. After its introduction in 1995 by an energy distributor in a pilot project in a Dutch municipality, in 2004 around 40% (2.8 million) of Dutch households and several hundreds organisations were buying green electricity, and more than twenty providers of varieties of the product had emerged. From the perspective of realising a sustainable or at least carbon lean electricity system this seems very promising as inherent to 'green' electricity is its renewable source base. From the perspective of realising systems change the new practice involves different competencies, routines and interaction patterns and signifies the creation of a path diverging from the fossil based trajectory of the electricity sector. The analysis will show, however, that as the new practice travelled from one organisation to another it became increasingly appropriated by the existing system and its path creation force was weakened.

To increase our understanding in processes of systems change this chapter provides a more detailed assessment why the concept emerged and how the introduction of this new concept within the electricity system triggered a sequence of changes in actors, networks, and institutions. The aim is furthermore to explain these changes and to analyse to what extent they

[1] This chapter contains a revised and expanded version of the history of green electricity drawing from Hofman (2001b, 2002 and 2005). Initial support for the case study by the EU-TSER program is gratefully acknowledged. The case study was part of the ENVINNO research project, see Schrama and Sedlacek (2003).

signify a process of path creation and escaping lock-in. The evolution of green electricity will be chronologically traced and the logic behind this evolution will be unravelled. The evolution of green electricity is explained as a multi-level process of changes in actors, networks, sectors, and governance structures. The emergence of the concept is understood as the outcome of changing routines and practices within a firm triggered by changes in the institutional environment in which it operates. The spread of green electricity is understood as a process of institutionalisation with new practices diffusing throughout the energy sector, with legitimacy gained through the formation of new networks and alignment of a variety of actors, and with increasing co-ordination between actors as emerging governance structures develop from the local to the national and international level.

While often 'radicalness' of an innovation is conceptualised as breaking with existing market linkages and technological competences (Abernathy & Clark, 1985), this chapter contends that the extent that an innovation diverts from existing paths, and involves radical innovation and path creation, is negotiated in the course of its development and dependent upon the way it becomes institutionally embedded, i.e. linked to existing and new institutions. The success of a new path, such as green electricity, in transforming an existing, or opening up a new, sociotechnical system is strongly related to the way institutionalisation of the emerging path unfolds.

6.2 The emergence of green electricity as a concept

In the early nineties a meeting took place between representatives of the electricity sector and the European Union in which liberalisation of the electricity sector was discussed[2]. The general view in the electricity sector was that due to homogeneity of the product, differentiation was difficult to imagine. One dissenting view was from Wiechers, chairman of PNEM[3], a regional distributor in the South of the Netherlands. Wiechers had experience with liberalisation of the telecommunication sector in his previous position as research director of KEMA, and expected that various ways of differentiation could be established. One aspect he had in mind was the creation of a more independent position in the market for the notion of 'sustainability'. As he pondered the implications of competition and differentiation within the electricity sector and possible applications based

2 This paragraph is based on personal communication with Ir. W.K. Wiechers, former chairman of PNEM and Essent, in April 2005.

3 Provinciale Noord-Brabantse Energie Maatschappij (Energy company for the Province of North Brabant). PNEM had a monopolistic position for distribution of electricity in the province of North Brabant until the electricity act of 1998.

on sustainability aspects he invented the concept of 'green electricity' (Wiechers, 2005). To be clear, green electricity as electricity based on the use of renewable sources already existed, however, selling 'green electricity' as a specific product to customers as something different from conventional electricity was new.

Invention of the concept of green electricity by an energy distributor

Before 1993 the energy distribution company PNEM was involved in several renewable energy projects that were mainly policy driven. In 1989 the company had published an environmental action plan with CO_2 reduction as an important objective. This was part of an agreement between the energy distribution sector and the Ministry of Economic Affairs, where an overall target for CO_2 reduction for the distribution sector was set and a framework for raising the financial resources for the various projects was introduced. In parallel the Ministry of Economic Affairs provided financial resources through subsidies on projects for energy saving, combined heat and power and renewable energy (see also Chapter 5). With the relative volatility and uncertainty of money flows from subsidies for renewable energy projects the question arose whether PNEM could achieve more independence through market funding of these projects and also differentiate the product in anticipation of increasing competition within the sector. In 1993 the idea emerged to have customers pay a premium for so-called 'green' electricity in order to use the premium for financing renewable energy projects, thus letting the market become more influential in deciding the development of renewable energy. This was also part of a broader process within the company with top management committed to further development of renewable energy, and this initially mainly policy driven commitment became more and more based on a strategy to develop a green profile for the company. Inside the company there was resistance to this concept because it complicated sale of electricity and implied changes in routines. Green electricity would have to be marketed and specific administrative channels would have to be created. Moreover, it implied that customers would pay more for something that physically is the same: the electricity provided to their house[4].

Various factors explain the emergence and acceptance of the concept. Developing a green profile in a strategy of product differentiation was part of the stronger market orientation the company developed in anticipation of

4 In this respect green electricity differs from most other green products that are not only processed differently (similar to the different process for green electricity relative to conventional electricity) but also have different qualities, such as different taste and absence of traces of pesticides (e.g. ecologically grown vegetables).

a liberalised market. The chairman of the company, as inventor of the concept, was committed to probe its potential and exercised his authority to initiate market research. Acceptance of the idea of green electricity was then strengthened by the outcome of the market research which indicated that a significant part of households had a positive attitude regarding the concept and was willing to pay a premium for electricity based on renewable sources[5]. Motivation for exploring the concept was also underpinned as it was expected to set various learning processes in motion deemed necessary in a competitive market, such as gaining insight in marketing methods and sales techniques. Until then routines within the company were based on consumers such as households that played a passive role within the electricity system, as they were 'captive' electricity consumers dependent on the electricity provider in their respective regions, and confronted with fixed prices. In a liberalised market the position of the consumers would become more active as they could freely choose products and services from different providers. It was anticipated that the required changes in routines to attract and bind customers could be facilitated by experiences with green electricity (Wiechers, 2005). In anticipation of liberalisation it also gave the company a competitive edge vis a vis other energy companies as they established the trademark green electricity[6]. A final factor facilitating the acceptance was that the company could better plan investments in renewable energy, as they would become more market and less policy driven. The company felt that market developments were more easy to influence and forecast by the company in comparison to policy (Van Gestel, 2001). The strategy to become less dependent on government subsidies was underpinned as the new 1994 Dutch government coalition of liberals and social-democrats announced, among others, budget cuts for energy subsidies to energy distribution companies.

Changes in the institutional environment facilitate the innovation

In the background for the innovation studied in this chapter three developments were crucial to explain the emergence of green electricity. The first development was the increasing attention for renewable energy as a

5 The market research indicated that around half of the customers would find an increase of the monthly electricity bill with around € 9 for green electricity acceptable (ECN, 1996).

6 A core consideration to establish a trademark was to prevent others from using the concept and terminology without applying the principles of green and newly installed power capacity. Use of the green electricity label and trademark and underlying principles was to be externally verified. This strategy was necessary to gain and maintain credibility of the product, and was based upon chairman Wiechers' experience at KEMA, the Dutch organisation responsible for testing electrical products (e.g. cables) and verifying compliance with safety and industrial standards.

strategy to reduce CO_2 emissions. After the oil crisis renewable energy was considered as an alternative for fossil-based electricity generation. As the climate change problem became more apparent, and also energy saving was not able to significantly reduce CO_2 emissions, renewable energy became a higher priority on the political agenda. This crucial change coincided with the first National Environmental Policy Plan of 1989 that reinforced the need to save energy and that adopted the strategy of identifying specific target groups (VROM, 1989). This signifies an important change in the relationship between the electricity industry and government. From 1989 on the electricity industry is targeted as a specific target group in environmental policy. The Ministry of VROM entered the policy network of the electricity industry next to the Ministry of Economic Affairs. Moreover, at the Ministry of Economic Affairs a change of energy policy took place. The perspective of the Ministry changed from security of supply to a complementary focus on energy saving and sustainability. In a follow up to the NEPP specific targets for the reduction of CO_2 emissions were set (VROM, 1990) and this was followed by a policy goal of 10% renewable energy in 2020 set in the third White paper on Energy in 1996. A voluntary agreement was reached in 1991 by the distribution sector and the Ministry of Economic Affairs to increase energy efficiency and reduce CO_2 emissions by energy saving measures, by increasing combined heat and power production, and by introducing renewable energy. This so-called environmental action plan (MAP) allowed utilities to impose a levy of 1.8% on the electricity price, the returns of this MAP-levy were then invested in projects on energy saving, combined heat and power production, and renewable energy (EnergieNed, 1994, 1997). The environmental action plan of the distribution sector was based on individual action plans of the distribution companies and covered the period 1990-2000. The distributors started to take an important role in the development of wind energy and later biomass, also as part of their environmental action plans.

The second important development was the change in institutional organisation of the electricity sector. The electricity act of 1989 enforced a new structure upon the electricity sector in which distribution and production companies were separated and some elements of competition were introduced. The new arrangement was expected to increase efficiency by increasing scale of the separated production and distribution companies and by reducing negative effects of vertical integration. The act allowed for some decentralised electricity production and import of electricity[7]. Distributors

[7] Import of electricity could take place by large consumers and by distributors. Both self-production and cogeneration by industry were allowed (see also Chapter 5 and Van Damme, 2005).

were allowed to produce electricity in up to 25 megawatt (MW) capacity plants, industrial companies are allowed to produce unlimited amounts of electricity (Arentsen et al., 1997). The act opened up ways for distribution companies to produce electricity outside the central generation capacity co-ordinated by the electricity producers through their co-operative organisation SEP[8]. Consequently distribution companies started generating electricity, in fact rather strategically. Apart from investing in decentral combined heat and power production that at that time could successfully compete with centrally produced electricity, distributors also engaged in several renewable energy projects.

A third factor was the process of liberalisation of electricity markets that was set into motion in the beginning of the nineties (a draft directive was already discussed in 1992) and culminated in the European directive of 1996 regarding common rules for electricity markets. Electricity companies were anticipating liberalisation of electricity markets and started to reorient their strategies towards competitive markets.

In overview then the process of liberalisation and institutional change within the electricity sector introduced competitive forces previously absent in the electricity sector and induced a process of change in the energy distributor. The increasing intensity of rivalry, the threat of new entrants, and the increasing power of consumers induced significant changes in organisational and evaluation routines in the company, which could be implemented in a period of reorganisation within the electricity sector. The increasing sense of urgency regarding the climate problem in society led the company to develop a profile where sustainability played an important role. The company started to view renewable energy as an opportunity instead of an obligation, which was facilitated by learning that took place in the earlier mainly policy-driven renewable energy projects of the company[9]. The search for new concepts was local in the sense that it originated from existing competences, built up experiences and changing routines within the company[10]. In combination, this led to the conception of green electricity as

[8] SEP stands for Co-operation of Electricity Producers (Samenwerkende Elektriciteits Producenten).

[9] Changing evaluation routines from the focus on problems and limitations to achievements and potential is a core element of path creation (Lampel 2001).

[10] It would have been much more unlikely that the company would have engaged in renewable energy development without this learning, as for example Nelson and Winter (1982), Kash and Rycroft (2002) and Rycroft and Kash (2002) have pointed out, search processes for innovation tend to be local in the sense that they built upon existing competences, experiences and routines.

part of a strategy to attract and retain customers on the basis of an established brand[11].

An unusual partnership to support the launch of green electricity

With market research indicating a potential for green electricity and the good fit of concept in the emerging 'green' and pro-active company profile, the company decided to launch green electricity through a pilot project in one city. A further outcome of the market research was the importance to establish credibility of the concept as customers indicated hesitancy to buy the green electricity as they were not prepared to trust an energy company regarding the sources of the electricity and the destination of the revenues, which were to be re-invested in renewable energy projects. Establishing guarantees regarding the 'greenness' of the product was considered a crucial factor for success (Wiechers, 2005). Therefore, the Dutch branch of the World Wide Fund for Nature (WWF) was approached to act as an external verifier of the product. Initial contacts were made at a high level between chairman Wiechers of PNEM and chairman Nijpels of the Dutch branch of the WWF followed by specific agreements at lower levels[12]. Participation of WWF was expected to increase legitimacy and trustworthiness of green electricity. For WWF collaboration with PNEM was part of its changing strategy from fund-raising for nature conservation with a neutral image towards more actively seeking opportunities to co-operate with parties in civil society (Glasbergen and Groenenberg, 2001). The co-operation of WWF with the energy utility also reflected the shifting culture of environmental organisations from one of protest to practical solutions (Hartman, Hofman and Stafford, 1999). The partnership fitted their changed strategy towards realising direct results, instead of working on agreements with government that are always subject to long-term implementation[13]. WWF supported green electricity to stimulate sustainable energy use, and to counteract climate change, which was viewed as one of the largest threats for global nature and diversity conservation. (Quarles van Ufford, 2000; Schöne, 2001). For PNEM the collaboration with WWF on green electricity gave the product the sustainable and trustworthy profile necessary to attract and commit customers. The positive results of a pilot project for green electricity

[11] Porter (1979) identifies five competitive forces that shape strategy: bargaining power of buyers, bargaining power of suppliers, the threat of new entry, the threat of substitutes, and the intensity of rivalry.

[12] Nijpels was the former Minister of Environmental Affairs (1986-1989) and at that moment mayor of Breda, a city in the province of North-Brabant close to the city where PNEM initiated a pilot project for green electricity. The chairman of PNEM, Wiechers, knew Nijpels personally.

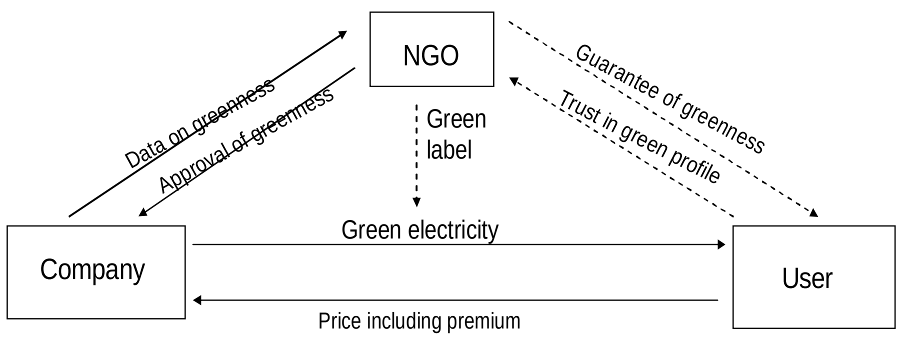
[13] Interview with co-ordinator of WWF quoted in Glasbergen and Groenenberg (2001: 1).

in the municipality of Tilburg[14] led to the launch of the concept in the province of North Brabant in 1995.

Analysis: green electricity, a new concept and new governance arrangement

Analytically, the introduction of green electricity and the partnership with WWF introduced practices in terms of product, organisational forms and modes of coordination within the electricity industry that radically broke with established ways of doing things. Accounting for the nature of electricity on the demand side was unprecedented. This introduced a new level of accountability and transparency within the industry, where exact details needed to be provided regarding the amount of green electricity produced, the inputs used (both in terms of energy resources and capital equipment/energy technology), and the numbers of customers using green electricity. Moreover, an external party was to verify these data in order to realise credibility of the product. All in all, this leads to the conclusion that the introduction of green electricity also included a new governance arrangement, implying new linkages, exchanges and contracts at the local level of the innovating company, NGO, and lead users (see Figure 6.1).

Figure 6.1 Governance arrangement for green electricity



[14] The project took place in May-June 1995 with support from the municipality. The first customer for green electricity was the alderman of environment of the municipality.

6.3 Early success with green electricity: policy and competitors' reactions

Although initially the number of customers opting for the new product was limited, with 400 customers after the pilot project (see Table 6.1), the launch was a success in several ways. An important objective was to make customers familiar with the product and to convince the general public of the reliability of its 'green' sources. As the media covered the launch of green electricity quite extensive, familiarity with the product rose steadily. The partnership with WWF, with the environmental organisation acting as a verifier of the renewable source for green electricity, gave the product the legitimacy it needed to transcend regular commercial product launches by giving it a flavour as being for the common good. Milestones in the introduction of green electricity are presented in Table 6.1. The new product also triggered reactions from other energy companies and from policy makers. Energy distributors started to imitate the concept by introducing other names for electricity based on renewable sources in their region[15]. Policy makers reacted by exempting green electricity from the regulatory energy tax that was introduced in 1996. The supply-oriented policy approach towards renewable energy was at that time shifting towards a stronger market orientation in line with a broader shift in energy policy and other policies[16]. The regulatory energy tax, initially initiated to promote energy saving behaviour of households, thus became an important driver of green electricity. Exemption of green electricity from the tax turned out to be a rather effective policy strategy to support the concept[17]. This side-effect

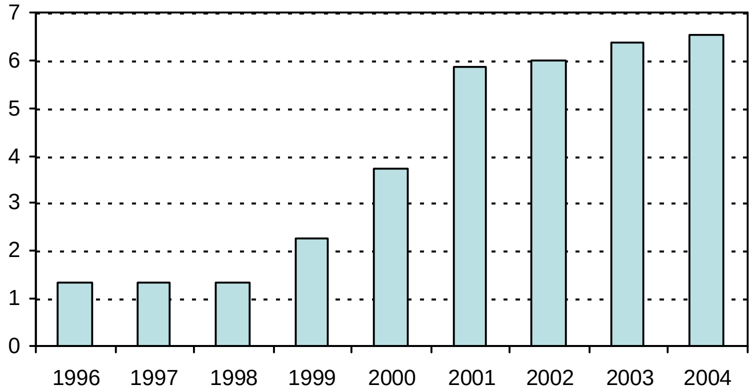
[15] At that time also other utilities had adopted the principles of green electricity, but under other names (nature power, eco-power) because of the trademark of Essent on the name green electricity. WWF promoted the general idea of green electricity and not the specific brand names.

[16] In 1994 a new government coalition was formed by liberal and social-democrat parties that had as its main motto: markets where possible, government if necessary. The Minister of Economic Affairs, Wijers, was a strong proponent of relying on market mechanisms which was reflected in the second energy policy note of 1996, and should also be explained in the context of an European process towards a liberalised European energy market. Both at the European and Dutch level also the relative successful liberalisation of telecommunications served as example (Oosterwijk, 2003).

[17] The magnitude and potential of this side-effect of the regulatory energy tax was only understood after it was initiated. One reason for the subsequent rises in the regulatory energy tax in the following years was the effect on demand for green electricity. Here some similarities can be seen with the introduction of the waste-water levy in the Netherlands in the seventies, intended to raise funds for the construction of public waste-water treatment plants but with the unintended but welcomed side-effect of reducing industrial waste-water production and stimulating innovation (Bressers, 1983, 1988; Bressers and Lulofs, 2003; Hofman, 2000). Both policies thus had important learning

became in turn one of the legitimising pillars for the regulatory energy tax[18]. The exemption initially led to a small reduction of the premium paid for green electricity, but with tax hikes in 1999 and 2000 it led to competitive prices for green electricity from 2000 on (see figure 6.2).

Figure 6.2 Evolution of Regulatory Energy Tax (in €cents per Kwh) for electricity consumption by households



First signs of institutionalisation of the new governance arrangement

After the introduction of green electricity by PNEM in the province of North-Brabant in 1995, other energy distributors followed PNEM's example through introduction of green electricity under similar names in their respective distribution areas from 1996 on. The principal elements of the governance arrangement introduced by PNEM were followed by all providers. Thus, it was guaranteed that not more green electricity was sold than was produced and additional income through green electricity sales was invested in new capacity based on renewable energy sources. Verification of these obligations was done by the WWF for most distributors, although occasionally another NGO acted as verifier. As of 1996, therefore, market-driven incentives accompanied policy-driven incentives in strategies for electricity generation based on renewable sources by the energy distribution

effects, both in terms of the interpretation of behaviour of target groups, as in terms of the nature of policies that could induce change in this behaviour. The wastewater levy facilitated the further implementation of the polluter pays principle in combination with propagating 'pollution prevention pays' for target groups; while the regulatory energy tax facilitated the concept of 'greening the tax system'.

[18] The initial objective of stimulating energy saving behaviour in households remained another pillar, and an evaluation study concluded in 2001 that the tax had resulted in lower energy consumption in the period until 2000 (SEO, 2001).

sector. Environmental action plans and the MAP-levy remained the main umbrella under which investments in renewable energy took place. The energy distributor PNEM was an exception: in 1996 they announced termination of imposing the MAP-levy to their customers, instead PNEM relied on funds built up through green electricity sales and on the intrinsic cost-effectiveness of energy-saving measures. PNEM remained committed to the goals of the environmental action plan but from their perspective imposing a levy had become unjustifiable to their customers in the light of the success of green electricity and the premium already imposed to buyers of the product. This step was not followed by other energy distributors but it was stated clearly that the funds generated by the MAP-levy were not to be used for investments in renewable facilities that served green electricity customers. In 1997 the number of green electricity customers had reached 25,000 in the Netherlands, with 10,000 green electricity customers for PNEM, while the average premium paid was 3.4 €cents per Kwh.

External accounting for green electricity production became more institutionalised as the third environmental action plan (for the period 1997-2000) was formulated. In the new action plan the distribution companies voluntarily agreed to achieve a goal of 3.2% of electricity sales based on renewable energy sources by 2000. Part of the agreement with the Ministry of Economic Affairs was also the establishment of a system of tradable green labels. These labels were issued based on production of electricity through renewable energy facilities. This implied that energy distributors could buy green labels from other distributors with renewable energy facilities in their respective regions. The green label system started in 1998 with EnergieNed acting as central registrar for green labels and verifying whether companies satisfy their obligations. The Treasury verified whether company really produced based on renewable energy facilities (EnergieNed, 2001a). Consequently, from 1998 until the end of the environmental action plan of the distribution sector in 2000 two parallel accounting systems were in place. One to verify the amount of renewable electricity produced in the framework of the environmental action plans of the energy distributors, and one to verify the ‘greenness’ of green electricity that customers contracted and to ensure that revenues based on green electricity sales were re-invested in new renewable energy facilities.

Table 6.1 Milestones in the introduction of green electricity[19]

Year	Activity
1990	PNEM publishes first environmental action plan
1991	Agreement on CO_2 reduction targets in environmental action plan for the sector, introduction of MAP levy
1993	Idea for green electricity emerges, business plan developed
1994	PNEM registers the product name 'green electricity' as a trademark
1995	PNEM approaches WWF to act as external controller for the green electricity
	Pilot project for 'green' electricity in the Municipality of Tilburg results in 400 customers who pay a premium of around 4 €cents on top of the normal electricity price of 9 €cents
	Green electricity introduced in whole Province of North Brabant resulting in 2350 customers at the end of the year (on a total of around 800,000 customers)
1996	Decision to construct biomass fired power station to secure green electricity supply in anticipation of growing demand
	Regulatory energy tax for small electricity consumers is introduced (1.5 €cents per kilowatthour, kWh), with an exemption for renewable energy
	Other energy companies also launch green electricity as a new product under other names (nature electricity, eco-electricity)
1997	Number of green electricity customers at PNEM rises to 10,000
1998	PNEM merges with MEGA, forming an electricity distribution utility for the provinces of North Brabant and Limburg, with 40,000 green electricity customers at the end of the year
	Energy distributors start with a tradable green label system
	Approval of environmental permit for the biomass power plant at Cuijk, agreements with Staatsbosbeheer to supply clean wood for the power plant
1999	National campaign for green electricity is started by WWF; the number of green electricity customers grows with 38 % (44,000) in four months)
	The utility Essent is formed through a merger of PNEM-MEGA with the distribution company Edon. Essent has 65,000 green electricity customers in November (on a total of around 2.4 million customers)
1999	The Cuijk biomass fired power plant starts its operations being able to serve around 70,000 customers of green electricity
2000	After a hike in the regulatory energy tax (to 4 €cents per kWh) prices of green electricity become competitive to conventional electricity, overall number of customers rises from around 120,000 in January to 200,000 at the end of the year
2001	Liberalisation of green electricity market at July 1st, customers are free to

[19] Data from this table based on interviews with Remmers (2000, 2001), Van Gestel (2001), Schöne (2001), Vis (2001), Wiechers (2005); information from Dutch newspapers, www.greenprices.com, Essent (2000) on green electricity customers.

	choose their own provider, the number of providers of green electricity rises to more than 20 and the number of customers rises sharply from 200,000 on Jan. 1 to around 800,000 at the end of the year
2002	Imported green electricity also becomes eligible for the exemption of the regulatory energy tax
	At July 1st the number of green electricity customers reaches 1 million in the Netherlands, market share of Essent is around one third
2003	Number of green electricity customers reaches more than 2 million, more than half supplied from power produced outside the Netherlands
	Exemption for regulatory energy tax is phased out and replaced by domestic support (feed-in premiums) differentiated for various types of renewable electricity generation
2004	Regulatory energy tax is renamed to energy tax
	In July the number of green electricity customers is estimated at 2.8 million.
2005	Formal obligation for electricity producers to inform consumers ex-post regarding shares of energy sources in their fuel mix and environmental impacts

Broadly supported marketing campaign raises interest in green electricity

From 1999 on the increase in consumers of ‘green’ electricity was rapid, with a growth rate of 47% between July 1st 1999 and January 1st 2000. Activities of the WWF were an important factor contributing to this increase. In September 1999, when green electricity had become available throughout the Netherlands, they started the campaign ‘Don’t Let the North Pole Melt, Go for Green Energy’ (Quarles van Ufford, 2000). The campaign, supported by the Ministries of Economic and Environmental Affairs, consisted of various advertisements in national newspapers, large scale actions with dressed up polar bears handing out 300,000 application forms on train stations, and with the North Pole, climate change, and green electricity as featured themes for one week in programs of one of the largest television broadcasting companies in the Netherlands. Overall the campaign led to acceleration in the monthly growth rates of green electricity from around 2500 to 10,000, and to a sharp increase in public recognition of the concept of green electricity (Schöne, 2001). For Essent, the company in which PNEM merged in 1999 with two other energy distributors, the number of green electricity customers gradually expanded from around 50,000 in 1999 to 300,000 in 2002 on a total number of around 2.4 million households to which Essent provided electricity. Essent’s main competitor, Nuon, offered the product ‘nature electricity’ starting from 1996 based on power production from solar, wind and hydro-power and realised growth rates similar to Essent.

6.4 Liberalisation of the green electricity market

In the development towards liberalisation of the Dutch electricity market the success of green electricity and the initial introduction of tradable green labels by energy distribution companies (in 1998) led to the decision to accelerate a separate liberalisation of the market for green electricity up to July 2001, earlier than the planned liberalisation of the regular electricity market for small consumers in 2004. This way both industry and consumers could gain experience with competition in the electricity sector. A parallel goal was to increase the share of renewable electricity in Dutch energy supply (PVE, 2000). A system of green certificates succeeded the green label system[20] and the green electricity scheme with WWF and became formalised with the independent grid operator TenneT[21] responsible for issuing the certificates (EZ, 2001). With these green certificates exemption from the regulatory energy tax could be obtained. Under the umbrella of TenneT a green certificate bank was established to keep electronic records of certificates and transactions[22].

Liberalisation of the green electricity market worked well to spur competition, with major providers engaged in extensive marketing campaigns and the number of providers growing from under ten in 2000 to above twenty in 2002. Strategies of providers increasingly started to diverge in terms of sources for green electricity, price-setting, and choice for domestic production or import of green electricity, as is shown in Table 6.3. With increasing competition and rising demand for green electricity strategies of individual providers also shifted as illustrated in Figure 6.3. Essent remained committed to domestically produced green electricity, but apart from 'clean' biomass for households also began to sell green electricity based on co-combustion of biomass within coal-fired power plants. To safeguard continuity of biomass supply it also increasingly had to import biomass. Nuon revoked its earlier decision to solely use 'pure' green electricity based on solar, wind and hydropower, and also started to offer another green variant based on biomass. The problem of finding renewable sites in the Netherlands also prompted its strategy to increasingly develop

[20] The green label system was introduced in 1998 as part of the renewable energy targets of energy distribution companies within their environmental action plan. At the end of the environmental action plan in 2000 it was concluded that the target for CO_2 reduction through renewable energy production (EnergieNed, 2001a). Landfill gas was responsible for more than half of the CO_2 reduction (EnergieNed, 2001a: 41).

[21] TenneT was established as independent operator of the high-voltage network under the Electricity Act of 1998.

[22] In a 'new economy' fashion the system was fully digital, as certificates were issued electronically and not in a paper version.

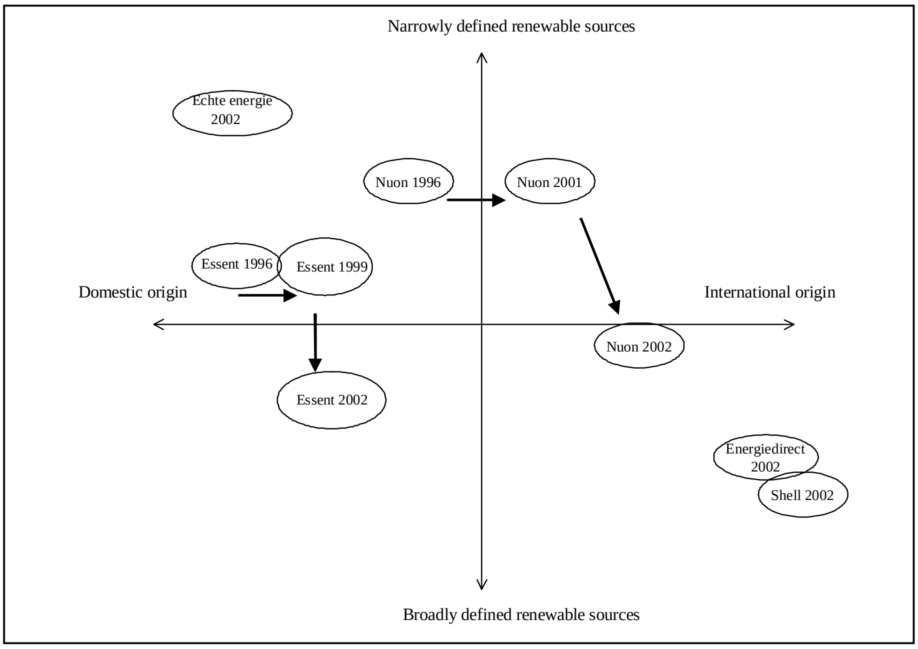
and acquire foreign facilities. Both companies remained committed to attracting new customers based on new or recently installed facilities and significantly increased the share of renewable electricity production within their production portfolio.

Table 6.3 Main providers of green electricity in 2002

Provider	**Product name**	**Sources**	**Origin**
Essent	'Green electricity'	Wind, water, biomass	principally Dutch
Nuon	'Nature current'	Solar, wind, water	Dutch and foreign
Nuon	'Green current'	Biomass, wind, water	mainly Dutch
Eneco	'Eco electricity'	Solar, wind, water, biomass	Dutch and foreign
Delta	'Zeeuws green'	Wind, biomass	Dutch
Remu	'Eco power'	Solar, wind, water, biomass	Dutch
Cogas	'Cogas green'	Biomass, some wind	Dutch and foreign
Rendo	'Green power'	Hydropower, biomass	mainly foreign
Echte Energie	'Clean power'	Solar, wind, water	Dutch
Energieconcurrent	'Green power'	Wind	principally Dutch
Energiebedrijf	'Green force'	Biomass, wind	Dutch and foreign
Shell	'Green power'	Swedish biopower	mainly foreign
Vattenfall	'Green power'	mainly hydropower	mainly foreign

(based on Kroon (2002: 15) and www.greenprices.nl)

Figure 6.3 Business strategies for green electricity: shifts and differences



After the opening of the Dutch retail market for green electricity in July 2001 the number of green electricity customers increased from about 250,000 to approximately 800,000 early 2002 and 1.4 million in January 2003. The sharp increase was caused by aggressive marketing campaigns for green electricity customers, pricing strategies that even led to green electricity offered below the price of conventional electricity (made possible by the favourable fiscal measures for green electricity), and the focus on green electricity as a tool for energy companies to attract new customers and establish their retail brand in anticipation of full liberalisation of the electricity market.

Support system dismantled due to opening up of green electricity market

Liberalisation of the market for green electricity also generated a not intended side-effect. The attractive compensation for green electricity, which consisted of restitution of the regulatory energy tax and a producer compensation for renewable electricity, the strong rise in customer demand for green electricity and the difficulty of initiating domestic renewable electricity facilities led domestic producers to increasingly import renewable electricity[23]. Also foreign energy providers started to offer green electricity to Dutch customers as from 2002 on renewable electricity exported to the Netherlands could qualify for the green certificate scheme and consequently become eligible for exemption from the regulatory energy tax. The result was that the growth in demand for green electricity after liberalisation was mainly satisfied by green electricity of already existing installations for renewable electricity generation, especially hydropower and biomass facilities (Kroon, 2002: 26; Reijnders, 2002). Differences in support schemes for renewable energy around Europe contributed to this, with only in the Netherlands the support system was mainly based on fiscal measures, whereas in most European countries the main schemes were supply oriented feed-in tariffs or demand oriented quota obligation or renewable portfolio standards (van Sambeek and van Thuijl, 2003). Although the threat of companies exploiting the mismatch between different policy frameworks was pointed out early (Boots et al., 2001), the strong rise in imports was not anticipated by Dutch government. Public and political discussion regarding the leakage of tax money through imported green electricity led to abolishment of the demand-oriented fiscal scheme in 2003. The system was replaced by subsidies for the electricity generated from facilities using

[23] If specific contracts were made with foreign suppliers regarding renewable electricity, this contracted electricity was also eligible for the exemption of the regulatory energy tax and production subsidies could be received. Provisions in the Green Tax Act (WBM in Dutch) prohibited making distinction between renewable production in and outside the Netherlands (Kroon, 2002: 10).

renewable sources, generally known as feed-in premiums. Innovative aspects of the new scheme were its differentiation for different renewable energy sources and the time-period of 10 years that was fixed as period of compensation[24]. Differentiation led to solar power, small hydropower, off-shore wind, and small 'pure' stand-alone biomass power plants receiving higher compensation per kilowatthour produced than on-shore wind, co-combustion of biomass, and the biomass fraction in waste.

Green electricity markets in other European countries

After the introduction of green electricity as a separate product based on electricity from renewables in the Netherlands the concept had diffused to other European countries, e.g. Sweden, Finland, UK, and Germany (van Dijk et al, 2003: 34). The success of the Dutch scheme in terms of the number of green electricity customers is however unparalleled in Europe. Bird et al. (2002: 531) for example estimate shares of 1 to 2% of customers opting for green electricity in a range of European countries compared to 13% in the Netherlands at that time. No systematic study is available to explain these differences but one can tentatively point at some typical elements in the introduction process and the institutional setting in the Netherlands. These include the initial role of WWF as third-party verifier and as promoter of the concept, the broad national support and information and marketing campaigns for green electricity prior to liberalisation of the green electricity market, the competitive price of green electricity due to exemption from the regulatory energy tax, the positioning of main Dutch electricity distributors in anticipation of an European electricity market with a focus on a green profile, the choice to accelerate liberalisation of the green electricity market in order to gain experience prior to full liberalisation, the intensive and aggressive marketing campaigns to attract green electricity customers once the market was liberalised, and the significant media attention for the green electricity market throughout the process.

The success of green electricity in combination with the difficulty of swiftly enacting renewable facilities in the Netherlands led Dutch energy distributors towards the end of the nineties to explore the possibility of importing green electricity. One way would be to extend the system of green labels to green electricity produced in other countries. This idea emerged at a project meeting where EnergieNed, the association of Dutch energy distributors, presented the green label system to other European project participants. In 1999 this resulted in the official start of RECS: the

[24] These elements were innovative in the Dutch setting but already general procedure in for example Germany.

Renewable Energy Certificate Scheme[25]. The bottom-up, market-driven initiative drew the attention of energy companies throughout Europe, and a two year test-phase was started in 2001 with certificate issuing bodies in fourteen countries and an international association of issuing bodies. RECS would thus provide a structure for the exchange of certificates under the various national labelling schemes. The aim was to illustrate reliability, credibility, effectiveness and quality of such a certificate scheme. The acceptance of RECS certificates by Dutch government, early 2002, significantly increased demand and credibility of the system. Other national governments were however much more hesitant to formally accept the RECS scheme and were mostly giving informal support (Dinica and Arentsen, 2003). A RECS certificate is issued for each MWh renewable energy produced, and early 2005 it was reported that more than 30 million certificates had been issued, while more than seventy companies were actively trading on a total of more that a hundred members. In parallel also policy developments occurred at the European level, in particular the 2001 directive on renewable energy that required member states to recognise guarantees of origin exclusively as proof that the underlying electricity is produced with renewable sources (EU 2001b). Early 2005 thus various systems for labelling existed in different countries, European legislation had developed in which national governmental systems for establishing guarantees of origin were required, and an international trading scheme had emerged. A process of convergence of various green certificate systems was underway, although significant progress was still needed to prevent fraudulent activities such as multiple counting of green electricity that enabled exploiting support schemes from various countries. In retrospect the emergence of the Dutch green electricity scheme followed by green labelling were initial steps in the process towards an European market for green electricity facilitated by tradable green certificates.

6.5 Expanding the supply base for green electricity

The success of green electricity also reinforced the need to develop the supply of electricity based on renewable sources. To illustrate how the success of green electricity at Essent triggered further processes of change the main strategy of Essent to secure electricity supply is examined. At the time of the introduction of green electricity, the first steps had already been taken to assess the feasibility of a biomass-fired power plant. The increasing demand for the green electricity product and the expected further expansion

[25] Information regarding the emergence of RECS is based on information of the website of RECS, www.recs.org, visited on Oct 26th, 2004 and on Dinica and Arentsen (2003).

of the product into other regions facilitated the decision in favour of building the Cuijk power plant. Electricity generation from the biomass-fired power plant would significantly reduce the risk that the company might let down potential green electricity customers because of limited supply. The problem of finding appropriate sites for wind energy in the Netherlands, the main competing alternative renewable source, also contributed to the advance of the company's biomass plans. Moreover, a speedy process was necessary in order to secure contracts for biomass supply, as, with increased competition, other companies were considering the opportunities for biomass-based electricity generation. For its biomass supply the company had to develop new networks because it was unfamiliar with available biomass sources and its logistics. Finding the right partners for the biomass input was probably the most risky part of the innovation, because the firm was setting out for a path towards an area in which it was totally inexperienced. First contacts were established with Staatsbosbeheer, the State agency for forest conservation, in order to gain insight in the availability and price of clean wood. Staatsbosbeheer was interested to participate because it was facing problems to finance the maintenance of forest, especially the process of thinning out. Collaboration with PNEM and later Essent was a way to make maintenance more cost-effective (Vis, 2000). The collaborative effort proved to be successful because both the company and Staatsbosbeheer shared the commitment that only clean wood available from the maintenance of forests would be used for the power plant. Staatsbosbeheer was committed to this because of their environmental responsibility and Essent because, according to the chairman of the board, the one time use of a wrong material could ruin the whole concept of green electricity (Van de Wiel, 2001; Wiechers, 2005). The fact that PNEM was able to secure a contract with Staatsbosbeheer was crucial because this was a reliable, trustworthy partner with its existence based on a green profile. The use of clean wood as a source for green electricity generation would be in line with the concept and was justifiable to customers. Feasibility studies concluded that clean low quality wood was available at a competitive price and suited for combustion. The company therefore prepared for the necessary procedures to obtain approval for the biomass fired power plant. Application for an environmental permit took place in 1997. The permit was issued in the beginning of 1998 after several impediments were overcome in the application procedure related to discussion regarding the character of the input (waste or biofuel), the actual sources for the biomass, the emission standards, and the energetic efficiency of the power plant[26]. These issues were new for the government agencies involved and had to be resolved to determine the kind of procedure that was to be followed and the kind of standards that were to be ordained (Hofman,

[26] Hofman (2001b) provides a more detailed account of these processes.

2001b). The company was able to progress through various rounds of discussions and negotiations because on the one hand it was a relatively powerful player in the Dutch electricity sector and had established good contacts both at the provincial and national level. And on the other hand the priorities of energy policy, for example expressed in the objective to gain experience with biomass based electricity generation, had the upper hand relative to waste policy. In April 1998 the construction of the 24 MWe biomass power plant was started by a consortium led by Siemens that made the best bid to the tender for the biomass-fired power plant (PNEM, 1996) and the plant commenced operation in August 1999. At the start of its operation, the biomass power plant was the largest wood combustion power plant for clean wood in Europe (Essent, 2000). As the contract with Staatsbosbeheer only satisfied part of the plants' resource demand the company had to expand its supplier network. This led to inclusion of a firm that delivered non polluted wood chips from pruned wood and of a joint venture of Dutch and German sawmills that delivered saw remains (Remmers, 2000). Establishing this network was important because of the shortage of suitable local biomass sources and the emerging plans of competitors to utilise biomass as a source for electricity generation. The contract with Staatsbosbeheer, where wood remains were to be collected in forests in an area with a radius of around 150-200 km (Vis, 2000), meant effectively securing some first mover advantage. Competitors had to tap wood sources outside the Netherlands or other biomass sources that were more complicated to generate electricity from. Another first mover advantage was the experience Essent gained regarding the logistics and large-scale use of biomass. This paved the way for several follow-up projects in which biomass was utilised on a large scale (Essent, 2002).

6.6 Explaining momentum for green electricity

In less than a decade a new product attracted close to three million customers in a sector previously characterised by stability and incremental change. The invention and launch of the concept of green electricity triggered a process of change in both producers and consumers in the electricity sector. Anticipation of the effects of liberalisation and responding to the increasing societal importance of climate change led the initial producers' efforts. One set of factors that explains how the company could diverge from the fossil-based trajectory thus lies in the build-up of pressures on and tensions in the previously stable electricity sector, which challenged the fossil base and institutional organisation of the system. The change of organisational routines in anticipation of liberalisation (e.g. new planning mechanisms due to loss of captive consumers, new strategic orientation vis à vis future competitors, development of marketing competences) in combination with the acquired competences in renewable energy production due to policy pressure led to the conception of green electricity. The company perceived increasing societal attention on climate change as an opportunity to distinguish itself from its competitors by developing a green profile and exploiting the shifting preferences of open-minded users. Cooperation with an environmental organisation was entered into in order to increase the product's legitimacy, which was also an illustration of the changed culture in the electricity distributor. This coalition of actors turned out to be able to successfully introduce the concept of green electricity, and a specific governance arrangement that supported it. Momentum for the new product increased as competitors imitated the product and familiarity with the concept became widespread.

The role of policy was significant for accelerated diffusion and scaling up of the concept through the introduction of the regulatory energy tax and the exemption of green electricity from the tax. The introduction of the regulatory energy tax, already discussed from the beginning of the nineties, happened to coincide with the emergence of green electricity. Due to the infeasibility of introducing an energy tax throughout Europe, the tax was solely oriented to small consumers to prevent inflicting costs and loss of international competitiveness of Dutch business. The main pillar of legitimacy on which the tax rested, providing incentives for energy saving of households, was soon complemented by another pillar of promoting demand for green electricity. The introduction of the tax also coincided with a shift in problem perception regarding slow penetration of renewable energy. A bias to supply-driven incentives and a lack of market incentives was increasingly seen as a main barrier for further spread of renewable energy. The second significant policy development was the decision to accelerate the liberalisation of the retail green electricity market prior to the full liberalisation of the retail market for conventional electricity. What was not well thought out however was the effect of mismatches between national regulatory frameworks on strategies of energy companies[27]. Especially in the light of governance arrangements to account for green electricity still in their

[27] Prof. Van Wijnbergen, a previous top-level civil servant at Economic Affairs, phrased it in a more outspoken way: 'It was plain stupidity; they just did not know what they were doing' (Köper, 2003). Also the fact that energy policy experts at ECN had clearly pointed these implications contributes to the conclusion that the dynamics and effects of companies shifting their strategies to exploit these differences were severely underestimated.

infancy, energy companies had a treat in exploiting these mismatches[28]. Moreover, the initial goal of stimulating demand in order to trigger new renewable energy production facilities was eluded for the moment as the sole focus was on being able to satisfy demand. In combination with the EU directive for renewable energy and anticipation of further trade in renewable electricity certificates the events in the Netherlands led to an increasing focus on developing more appropriate governance arrangements.

The success of the green electricity concept also facilitated the decision of Essent to construct the biomass-fired power plant. Other factors were the importance of the power plant for realising the goals of the environmental action plan, and the company's strategy to be the front-runner in gaining experience with the logistics of large-scale biomass-based electricity generation. The company's ability to build a network in which skills, know-how and experience regarding the logistics of the biomass resource were accumulated, and its relative power within policy networks, were crucial factors for the power plant to succeed.

The case points up several aspects that are relevant to success in diverging from established paths: for example, in response to climate change. One is the important role of 'prime movers', such as in raising awareness, undertaking investment and providing legitimacy for new technologies or products (Jacobsson and Johnson 2000). Clearly there is risk involved in developing new products and technologies, and companies often tend to play a strategic game of wait-and-see, especially when new product or technology characteristics are more a reflection of policy pressure than of market demand. This case shows that if a company is able to read the latent demands of the market it may be able to gain some first-mover advantage. As prime movers may trigger wider transformation processes, as in our case through the acceleration of the greening of the tax system and further institutional change towards labelling of electricity flows, they are likely to be well placed to take advantage of the momentum that is generated. Second, the case has also shown that in order to be able to acquire first-mover advantages the company needed to build new networks that provided the competences and legitimacy it lacked individually. Other research has confirmed that the building or restructuring of networks is required to diverge from familiar paths and to establish new practices (Rycroft and Kash 2002). Third, the introduction of a new product or technology often needs to be accompanied by further institutional change in order to gain momentum and to change a technological system. Processes of standardisation, building

[28] Some pointed out the possibility of double dividend: electricity imported from facilities that had received domestic support also could become eligible for exemption of the Dutch regulatory energy tax.

legitimacy, adapting regulatory frameworks, and developing alternative governance arrangements are examples of this. The way these institutional changes unfold form a crucial part of the change process and largely determine the nature of the transition.

6.7 Filling the institutional void: defining green electricity and its market

The emergence of green electricity in the energy system in the Netherlands triggered a sequence of events and changes in the Dutch electricity system. While the case shows that the mobilisation of actors under the right conditions can create strong drivers for change, the main difficulty is to direct these driving forces in a sustainable direction towards fundamental change of systems of production and consumption. While the concept initially developed was relatively ‘pure’, with green electricity domestically generated through new installations of mainly wind and ‘clean’ biomass and revenues re-invested in renewable energy development, it lost its virginity when the concept travelled to other organisations. The boundaries of clean biomass faded away as the organic fraction of waste became acceptable. The boundaries of new installations faded away and also co-combustion of biomass with coal in coal-fired power plants became acceptable. And, above all, the incentive for and urgency of developing domestic facilities eroded with the eligibility of imported green electricity for the tax exemption. The leverage of rising demand for accelerating domestic renewable energy facilities impacted investment strategies of some companies but was not utilised to signal the urgency of more broader institutional changes[29] or more specifically to reduce more fundamental institutional barriers, such as the volatility of policy support schemes (Dinica, 2003); complex, long lasting, and uncertain procedures for unlocking potential locations for renewable energy facilities; and lack of structural local involvement in and commitment to expanding renewable energy bases (Coenen and Menkveld, 2002). Green electricity thus became an easy profit maker for foreign energy companies (and domestic importers) that already had renewable electricity installations (mainly hydropower). The main reason for these developments was that green electricity was developed in an institutional void[30]: the definitions for green electricity had to be developed, and the definition over what constituted the market and which rules were guiding it, had to be developed.

[29] Also the timing of and the mouthpiece of these signals is crucial, for example the plea for a Deltaplan for a sustainable energy supply by the socio-economic council (SER) in 1999 did not receive much attention.

[30] Hajer (2003) introduces and explains this term more specifically.

What is striking that in these processes the main actors were energy companies and environmental NGO's, while governments were mostly reactive and hesitant in taking up a position. The Ministry of Economic Affairs acknowledged it did not want to become involved in the complex discussions about what constitutes 'clean' and 'dirty' biomass and how these relate to different conversion technologies. The most progressive energy companies therefore developed guidelines in collaboration with environmental NGO's and appeared to be transparent with regard to the inputs that were used in comparison to other companies. Developing clear principles and developing governance arrangements that could secure acceptable levels of accountability and transparency regarding application of those principles became more difficult as the concept travelled to other organisations. Initial principles of developing new facilities and re-investing green premiums in those facilities became blurred, just as what qualified for green electricity became more diffuse. The initially more fundamental principles still guide individual companies, but lost their leverage for the market as a whole. Regaining that leverage will be a precondition for society as a whole to return to the path of escaping lock-in.

6.8 Green electricity as a transition path: success and failure factors for systems change

The chapter unravels the factors behind the invention of the concept by an energy distribution company and behind its successful introduction. At the actor level it explains how a process of change in corporate culture and marketing strategy provided footing for the concept and was motivated by internalisation of external policy and market pressures emerging from climate change policy and liberalisation. It also reveals how the company revised its innovation strategy to cope with increasing demand of the product. In the process the company was able to reap some first-mover advantages but it also experienced serious problems as it deviated from the familiar path of fossil fuel based electricity production and delivery. Some of the main problems were the lack of the firms' trustworthiness regarding the 'greenness' of the electricity and its unfamiliarity with biomass resource contracting outside the established channels for fossil fuels. Crucial in overcoming these obstacles were several partnerships the company built with actors outside the electricity sector. Through the formation of new networks the company was able to acquire competences and built credibility and legitimacy for the new product. As the new product was imitated by other companies, however, the commercial aspects of the product gained dominancy over the sustainability aspects of the product. Paradoxically, the relations between the energy company and the environmental NGO on the one hand opened up the system and created a new image and new venues, but on the other hand it also enabled other energy companies to commercialise their products on the trust which was created. In this process of institutionalisation, there were no actors who could safeguard the sustainability dimension of green electricity. Moreover, institutionalisation did not take place in a complete void, but was nested in the structure of European liberalisation of electricity markets with constitutional rules such as the establishment of a 'level playing field'. In practice there was never a level playing field, as some Dutch energy firms were having a hard time developing domestic renewable opportunities, other, sometimes foreign, energy companies sold green electricity based on already existing power plants abroad. The inability to specify rules to block imports based on existing installations weakened the change process significantly. Moreover, instead of mobilising a search for ways to satisfy demand domestically, most efforts were focussing on ways to repair the mismatch between Dutch and European policy frameworks. While this repair was effectively sealed with the shift towards production subsidies that reduced attractiveness of exports of green electricity to the Dutch market, it stills remains to be seen whether the concept is able to regain its initial momentum for change.

Chapter 7

Exploring transitions through sociotechnical scenarios[1]

7.1 Introduction

Current scenario methods are not entirely suited to explore possible system innovations. They lack attention to the co-evolution of technology and society, and to insights from innovation studies and sociology of technology. This chapter develops a new tool: sociotechnical scenarios. The tool is illustrated with two scenarios in the electricity domain, sketching transition paths to more sustainable systems. Also strategic policy recommendations are derived from the two scenarios.

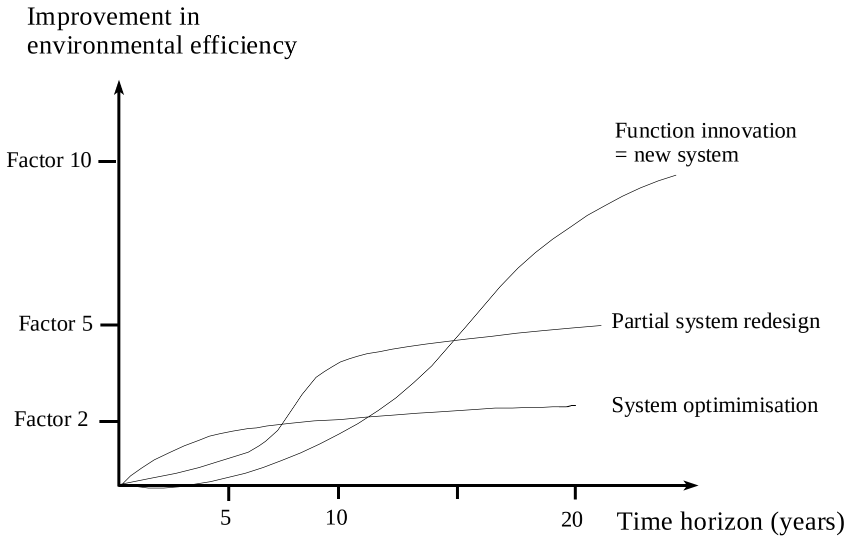
Modern societies face huge challenges related to existing sociotechnical systems which are difficult to tackle without fundamental change. One example is the transport system, which faces structural problems like congestion, atmospheric pollution (NO_x and particulates), and CO_2-emissions. And the energy system suffers from high CO_2 emissions and fuel supply uncertainties. Such problems are deeply rooted in societal structures and institutions. In transport systems and energy systems there are promising new technologies with better environmental performance. But many of these new technologies are not (yet) taken up. This is partly related to economic reasons, but also to social, cultural, infrastructural and regulative reasons. Existing systems seem to be 'locked in' at multiple dimensions. Hence, recent articles have widened the analytical focus from artefacts to socio-technical systems (e.g. Unruh, 2000; Jacobsson and Johnson, 2000; Berkhout, 2002). Socio-technical systems consist of a cluster of elements, including technology, regulation, user practices and markets, cultural

[1] This chapter is a revised version of an earlier published article: Hofman, Elzen, and Geels (2004) Sociotechnical scenarios as a new tool to explore system innovations: Co-evolution of technology and society in the Netherlands' electricity domain, *Innovation: Management, Policy and Practice* 6, 2: 344-360. Funding of research projects underlying this chapter by the Dutch Scientific Council and NOVEM, under the energy research programme, is gratefully acknowledged.

meaning, infrastructure, maintenance networks, and supply networks. Sociotechnical systems are stable, because the elements are aligned and woven together. Yet, to solve structural problems in society, we need transitions in sociotechnical systems. Such system innovations not only involve technological changes, but also changes in user practices, policy and regulation, infrastructure, social networks, and culture.

Policy makers, NGOs, large firms and others show substantial interest in system innovations. The Stockholm Environment Institute, for instance, published a book on the Great Transition (Raskin et al. 2002). The American National Research Council (1999) and the Dutch Research Council NWO have made transitions part of their research portfolio. And the Dutch government gave transitions a central place in their fourth National Environmental Policy Plan (VROM, 2001). They think that system innovations promise large improvements in environmental efficiency as shown in Figure 7.1.

Figure 7.1 System optimisation versus system innovation (Weterings et al., 1997)



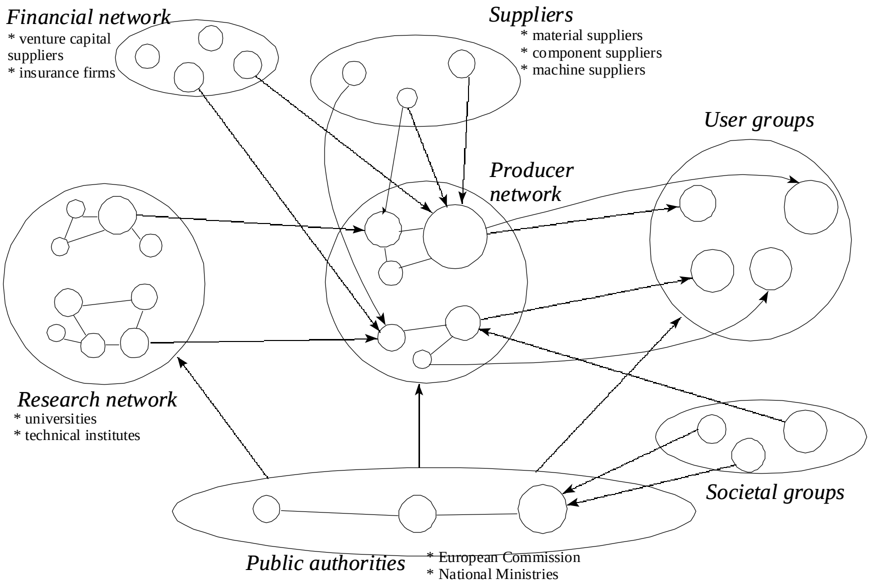
But transitions are complex, uncertain and involve multiple social groups. Hence, decision makers struggle with the question on how to know and influence possible directions of such transitions. Scenarios or forecasting exercises are often used to guide such strategic decision-making. The central argument developed in section 7.3 is that existing scenario methods are not entirely suited to explore system innovation. They are often based on too simple assumptions about the dynamics of technological change, and ignore the co-evolution of technology and society. Therefore, a new scenario tool is developed, sociotechnical scenarios (STSc), tailored to explore transitions and system innovations (section 7.4). This new tool does not replace existing scenario methods, but can complement them. A strength of the method is that it builds explicitly on a scientific transition theory, described in section 7.2. The tool is illustrated in section 7.5 with two sociotechnical scenarios for the development towards a more sustainable electricity system. Section 7.6 derives some strategic policy suggestions from the scenarios. The chapter ends with conclusions about the added value of STSc.

7.2 Transition theory

To understand technological transitions a multi-level perspective is used that builds on insights from innovation studies and sociology of technology. Sociology of technology emphasises the interrelatedness between technical and social change and the interaction between social groups (e.g. Bijker et al., 1987; Bijker and Law, 1992). At the heart of the transition theory are three ‘levels’ and the interactions between them. The meso-level is formed by socio-technical regimes. Socio-technical systems are actively created and maintained by several social groups (Figure 7.2). Their activities reproduce the elements and linkages in sociotechnical systems and are coordinated and aligned to each other. This is represented with the concept of socio-technical regimes, which refers to the cognitive, normative and formal rules that guide activities of social groups. By providing orientation and co-ordination to the activities of relevant actor groups, sociotechnical regimes account for the ‘dynamic stability’ of ST-systems. This means that innovation still occurs but is of an incremental nature, leading to ‘technical trajectories’ and path dependencies.

The micro-level is formed by technological niches, the locus for radical innovations (‘variation’). As their performance is initially low, they emerge in ‘protected spaces’, which shield them from mainstream market selection. Niches thus act as ‘incubation rooms’ for radical novelties. Niches are important, because they provide locations for learning processes about the technology, user preferences, regulations, infrastructure, symbolic meaning etc. Niches also provide space to build the social networks that support innovations. These internal niche processes have been described under the heading of strategic niche management (Kemp et al, 1998, 2001).

Figure 7.2 Social groups which (re)produce ST-systems (Geels, 2002b: 1260)



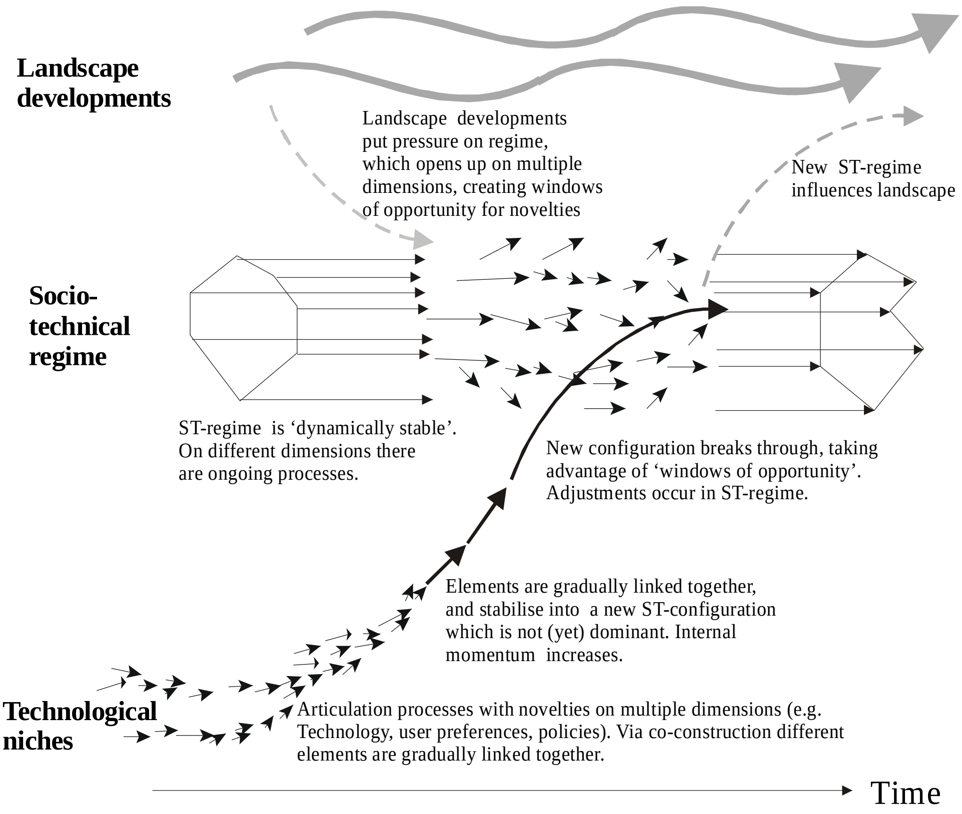
The macro-level is formed by the socio-technical landscape which refers to aspects of the wider exogenous environment (e.g. globalisation, environmental problems, cultural changes). The metaphor 'landscape' is used because of the literal connotation of relative 'hardness' and to include the material aspect of society, e.g. the material and spatial arrangements of cities, factories, highways, and electricity infrastructures. The landscape forms 'gradients' for action; they are beyond the direct influence of actors.

The relation between the three concepts can be understood as a nested hierarchy or multi-level perspective. Regimes are embedded within landscapes and niches within regimes. Transitions and system innovations come about through the interplay between dynamics at multiple levels and in several phases (see also Rotmans et al., 2001). In the first phase, novelties emerge in niches in the context of existing regimes and landscapes with their specific problems, rules and capabilities. New technologies often face a 'mismatch' with the established economic, social and/or political dimensions (Freeman and Perez, 1988). Hence, novelties remain stuck in niches. In niches, actors improvise, engage in experiments to work out the best design and find out what users want. In the second phase the novelty is used in small market niches, which provide resources for technical specialisation. Engineers gradually develop new rules, and the new technology gradually improves, as a result of learning processes. The third phase is characterised by a breakthrough of the new technology, wide diffusion and competition with the established regime. On the one hand, there are internal drivers for breakthrough. For instance, actors with interests may push for further expansion of the technology. Or price/performance dimensions gradually improve. On the other hand, breakthrough depends on external circumstances, i.e. 'ongoing processes' at the levels of regime and landscape, which create a 'window of opportunity' (see Figure 7.3). There may be changes at the landscape level, which put pressure on the regime. There may be internal technical problems in the regime, which cannot be met with the available technology. There may be negative externalities, which are problematised by 'outsiders', e.g. societal pressure groups (e.g. Greenpeace), outside scientific professionals, or outside firms (Van de Poel, 2000). Or there may be tensions within the existing regime, because of changing user preferences or stricter regulations. The key point of the multi-level perspective is that system innovations occur as the outcome of linkages between developments at multiple levels. As the new technology enters mainstream markets it enters a competitive relationship with the established regime.

In the fourth phase the new technology replaces the old regime, which is accompanied by changes on wider dimensions of the sociotechnical regime. The new regime may eventually influence wider landscape developments. This generic multi-level perspective can be further refined in terms of transition routes. Geels (2002a) distinguished two routes: (1) technical substitution and (2) broad transformation. In the substitution route, socio-technical regimes are relatively stable until the breakthrough of new technologies. The wide diffusion into mainstream markets triggers wider changes, and may cause established producers to fail (Schumpeter's 'gales of destruction'). On the level of regimes, this route can be described with punctuations between relatively stable socio-technical configurations. It is called 'substitution' because the user substitutes one technology for another with relatively little change in meaning and behaviour.

In the transformation route, much more is at stake than a technical substitution. There may also be changes in user behaviour, cultural change, policy changes, infrastructural change, etc. The loosening up of the existing regime may create windows of opportunity for multiple novelties and stimulate actors to experiment with many technical options. Often, these novelties do not break through individually but first merge with each other or with parts of the regime. The typical pattern in broad transformation is that the regime (usually under pressure) first opens up and creates room for a wide variety of niches. One or more of these may then start to grow at the expense of the existing regime until they become the new dominant regime.

Figure 7.3 A dynamic multi-level perspective on system innovations (Geels, 2002a)



Then the regime tends to close in again, reducing the room for niches. Below these general longer-term patterns some shorter-term mechanisms can be distinguished. One example is the sailing ship effect, which means that the existing regime defends itself against upcoming niches via technical improvements (after sailing ships which added more sail and masts to counter the threat of steamships). Another example is the mechanism of niche-accumulation. A new technology diffuses via successive domains of application and market niches. A third mechanism is hybridisation: the merger of two technical options to create something new (e.g. the merger of the gas turbine and the steam turbine into combined cycles (Islas, 1997). A fourth mechanism is that new technologies may induce (initially small) groups of users to change their behaviour and develop new user practices. Such new user patterns emerge through 'learning by using' (Von Hippel, 1988).

Table 7.1 Overview of scenario methods and exemplar projects

Project description	Method	Strengths (+) / weaknesses (-)
Forecasting		
IPPC (2000): Global greenhouse gas emission scenarios up to 2100	Combination of four basic narratives ('storylines') and more detailed modelling and quantification (forecasting)	(+) Aggregate attention for co-evolution; focus on uptake of radical technologies (-) Learning processes anticipated but not explained; limited focus on actor strategies
Foresight		
Shell (2001): Scenarios of societal change and impact on business and energy development (2020 and 2050)	Descriptive scenarios complemented by quantification of some main factors (demographics, incomes, energy demand, fuel and technology mix) used to support long-term business strategies.	(+) Focus on social and technological driving forces; taking into account discontinuous change; multi-actor and multi-level processes (-) Limited interaction between societal and technological change; No specification of learning processes; Macro-orientation and lack of actor interactions at lower levels
Backcasting		
SusHouse (Vergragt, 2000): Scenarios for sustainable household functions (food, shelter, clothing) by 2050 in several European countries	Creativity workshop with stakeholders to produce ideas about factor 20 sustainability improvement for the functions; followed by construction of design oriented scenarios; and by an environmental, economic and consumer assessments	(+) Develops alternative fulfillment of functions based on technological and social change; strong focus on consumers as important actors (-) Limited insight in how co-evolutionary paths towards alternative future takes place; anticipates learning but does not specify how this may lead to uptake of radical practices
Technological roadmapping		
EPRI (1999): Electricity technology roadmap to 2050 for the US	In a process with around 100 stakeholders (mainly technically oriented) a vision is developed regarding the long term potential for electricity as a clean, growth enabling technology, accompanied by a R&D agenda to realise this	(+) Starts from premise of importance of institutional processes for technological change; takes into account long term technological change featuring hybridisations, cross-cutting technologies (-) Very limited co-evolution through strong bias on technological change; lacks focus on interaction processes and learning
Breakthrough methods		
Noori et al (1999): Assessment of breakthrough potential of new product or service, application for electric vehicle	An umbrella approach that assesses future goals, needs, desires, and product development direction, and works backward to the present to determine what steps must be completed to reach that state	(+) Takes into account importance of changing user preferences, cultural factors for uptake of breakthrough technologies (-) Limited explanation how learning processes occur; restricted focus on innovator and consumer as actors

7.3 Strengths and weaknesses in existing scenarios methods

There are several scenario methods and projects for the long-term exploration of fundamental and systemic change processes (30-50 years). Table 7.1 gives an overview of existing scenario methods illustrated by exemplar scenario projects, selected out of a larger evaluation of around twenty scenario projects. A short characterization is provided in terms of the type of scenario and the nature of the method. In the third column, we evaluate how the scenarios score on characteristics of system innovations (strengths and weaknesses).

From this overview we conclude that none of scenario projects and methods encompass all characteristics of system innovations, although most score well on some of them. One basic deficiency is the lack of a clear conceptual framework regarding the way transitions occur. Technological change is often conceptualised in a simple way, e.g. as determining force or as aggregate learning curve. There is a lack of attention for actors, their decisions, interactions and learning processes, and the way these shape twisting transition paths. The pathways in most scenarios seem to be determined mainly by external factors. But, of course, choices by actors in regimes and niches are also important for future trajectories, bifurcations etc. Macro-, meso- and micro-levels should all be included. These conclusions do not mean that existing scenario methods are irrelevant. They may fulfil useful functions to explore aspects of transitions. But to encompass the entire complexity of system innovations, there is a need for a new tool.

7.4 Sociotechnical scenarios and guidelines for their construction

Scenarios are usually constructed following a sequence of steps (Table 7.2).

Table 7.2 Methodological steps in scenario building

Step 1	Identify focal issue or decision
Step 2	Make an empirical analysis of aspects and processes which directly and indirectly influence the focal issue
Step 3	Rank aspects and processes by importance and uncertainty
Step 4	Select scenario logics (skeleton): give different scores to those aspects and processes which are most uncertain and have most effect
Step 5	Flesh out and write the scenarios
Step 6	Derive implications for initial decision

Our focal issue are system innovations, in this paper regarding the electricity domain. We make our contribution mainly to step 2 and 4, in the sense that we use an explicit theoretical approach for the empirical analysis of the electricity system and the writing of the scenarios. Because co-evolution of technology and society is at the heart of the approach, we call the new tool sociotechnical scenarios (STSc). Using the multi-level perspective, we analyse the main variables in the electricity regime, promising niches and possible landscape developments, and indicate how important and uncertain they are. We also use the multi-level perspective to think and write about possible future transition paths. The perspective helps us identify plausible transition paths. Patterns and mechanisms can be used to include more fine-grained sociotechnical dynamics[2] (Geels, 2002a). Some examples are:

– Regimes trying to counter demands on the regime and the threat of niches that emerge as solutions to those demands via various improvements (e.g. coal power producers in the Netherlands starting with co-combustion of coal with biomass to reduce the pressure of a variety of more carbon friendly alternatives);
– Niche cumulation: technologies develop and diffuse through different domains of application or niche markets (e.g. photovoltaic power moving from use in satellites to stand-alone systems to grid-connected systems or fuel cells from use in satellites to use as back up power to use for super high reliable power production);
– Hybridisation: the merger of two options to create something new, e.g. the merger of the gas turbine and the steam turbine into combined cycles (Islas, 1997); or the merger of the fuel cell and the gas turbine into a more efficient power generating system.
– New technical developments triggering new societal developments, e.g. the introduction of ICT leading to the new economy, or the emergence of the internet as a new means for information gathering and recreation.
– Emerging new user patterns: some technologies may induce (initially small) groups of users to change their behaviour and these groups may grow under specific circumstances; this may be triggered by a variety of reasons like creating new opportunities, distinction, cost-performance considerations, etc. In transitions, often a combination of such reasons is at work.

We summarise the main characteristics for two scenarios that have been constructed and that incorporated the aforementioned patterns. These characteristics are then translated into plausible dynamic transition paths.

[2] A current project is underway in which a more specific methodology for the construction of sociotechnical scenarios is developed.

Table 7.3 shows that the main differences are not so much the consequence of different technologies being used, but follow from alternative actor strategies and choices. In the first scenario, traditional power producers are the dominant actor, utilising gasification technology on a large-scale through processes of hybridisation. Developments in the US provide an important stepping-stone for the niche through its focus on coal gasification. In the second scenario, energy distribution companies are a crucial actor, working together with gas utilities, which seek opportunities to increase their market share by the development of micro cogeneration in coalition with other actors. Table 7.3 provides an overview of some of the main characteristics, drivers, networks and differences and similarities of the two scenarios.

7.5 Towards a sustainable electricity system: Illustration of two transition paths

This section describes two sociotechnical scenarios, illustrating two different transition paths towards a sustainable electricity regime. These paths follow the contrasting routes described in section 7.2 (technical substitution and wider transformation) with the intention of providing some lessons for transition policy (in 7.6). In the first scenario renewable sources are gradually integrated into the existing regime; in the second scenario a broader transformation of the regime takes place towards distributed generation. Both stories build upon the static backbone, provided by Table 7.3. The stories are written in the past tense as histories of the future and build upon dynamics in the electricity sector in the past decade. Therefore we start with an introduction of the dynamics in the last decade of the past millennium, after which the two stories begin to diverge.

7.5.1 1990-2000: The Electricity Regime Opening Up

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 (see for example Hughes, 1983; Hirsh, 1999; Unruh, 2000). In the last decades, however, the electricity regime opened up. Its social network became unstable as national government aimed to exercise more control, and industrial and societal actors challenged guiding principles of the regime (Joskow, 1998; Hirsh, 1999; Patterson, 1999). The regime was long able to deal with increasing external demands such as efficiency and environmental emissions without fundamentally changing the sociotechnical configuration.

Table 7.3 Characterisation of the two scenarios and transition paths.

	Large scale integration of renewables	**Towards distributed generation**
Initial Niches	- Biomass co-combustion in coal--fired power plants - Offshore wind power farms - Coal/Biomass gasification; based on international niche proliferation - Fossil generation with CO_2 separation, storage	- Combined heat and power production with small scale electricity generation technologies - Local power generation because of overburdened grid - ICT demand for reliable power - New housing districts with low energy impact
Main differences	Large scale power plants at international level, based on biomass gasification, wind power, photovoltaics and hydrogen facilities; international electricity highway; international coordination of electricity flows	Dominance of local based networks with electricity generation units dimensioned to local demand; high voltage grid serves as back up; integration of number of energy technologies/sources such as pv, wind, biomass, fuel cells, turbines
Main similarities	Gas and hydrogen important bridging resources, fuel cells important energy technology also in hybrid combination	Gas and hydrogen important bridging resources, fuel cells important energy technology also in hybrid combination
Drivers		
Landscape	Liberalisation, EU integration, Climate change	Liberalisation, ICT, Sustainability/climate change
Regime	Increasing international character of regime, uptake of renewables by regime	Battle between electricity producers, multi-utilities and gas companies; changing position of consumer
Niches	Hybridisation of niches with regime; niches adapt to dominant design of central station electricity	First niches because of differentiation in regime; niches slowly built new power system design of distributed generation
Barriers	Mismatch of renewables with regime, problems of integration into existing regime	Design, regulation, routines based on central station electricity regime, not on local generation with local grid
Dominant networks	Networks with traditional electricity producers, distributors and government actors; oil and chemical sector becomes part of electricity regime	Networks of energy distributors, engineering firms, construction companies, housing associations and municipalities
Policy	Strengthening of international grid, EU policies, support for green electricity, and labelling of electricity flows	Local energy policy, stimulation of alternative infrastructures, integration of energy in built environment

The process of liberalisation, however, led to increasing tension within the social network of regime actors. For example in the Netherlands, 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 a sign of the loss of control by regime actors (Arentsen et al, 2000). 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 (e.g. energy distribution companies and environmental NGOs). With the emergence of new markets, exchanges and actors old social networks vanished and new networks emerged. The landscape developments of liberalisation, climate change and information technology increasingly penetrated the electricity regime and uncertainty over the future direction and speed of developments in electricity generation and use became high (e.g. van Hilten et al., 2000).

7.5.2 Scenario 1: Large Scale Integration of Renewables in the Electricity Regime

2000-2010: Liberalisation creates tension in the regime

Five landscape trends were driving further change in the electricity regime with liberalisation as the most pervasive one. In combination with European integration, climate change, ICT and the new economy, and security threats it led to a totally different setting in which the electricity regime was operating.

Several patterns of change were visible in the electricity regime. Established power producers engaged in international price competition in order to realise full utilisation of their power plants and to satisfy customers' demand for low prices. A sharp increase in international trade in electricity was the consequence. To guarantee a European free market the EU intensified its role in harmonising the processes of liberalisation of national electricity sectors and in safeguarding sufficient capacity for crossborder electricity transport. The more volatile market conditions also demanded more flexible power plants that could produce efficiently at different loads and had short start up times. This reinforced the shift towards gas within the fossil fuel mix because of the higher flexibility and efficiency of the gas turbine relative to the more capital intensive and rigid coal-fired and nuclear power plants (see also Shell, 2001). Large oil and gas companies such as Shell were also able the enter the electricity generation market by investing in combined cycle gas turbines that produced electricity and heat fuelled by their own gas supply. This gave them an edge over other power companies with gas-fired power plants that had to cope with volatile market conditions for gas.

The emancipation of the previous mostly passive electricity users led to various changing user preferences. The penetration of ICT and the new economy, for example, led on the one hand to higher quality and reliability demands while on the other hand it facilitated e-commerce in the electricity system. Also, industrial users settled one contract for the combined purchase of heat and power or different contracts for base-load and peak-load electricity delivery. Households with commitment to sustainability were keen on a green profile of electricity. Especially energy distributors and new entrants were developing innovative products and services that could meet the changing user preferences.

Alternative strategies were enabled by available niche technologies that better suited new user preferences. In the Netherlands the concept of green electricity provided momentum for investments in especially wind and biomass. Constraints for wind energy on land (regulatory, societal) led to increased expectations and investments in off-shore wind farms where these constraints were less complex to deal with. The biomass niche and its constituency expanded as it hooked up with the regime. To improve their carbon profile and to reduce Dutch political pressure, coal power producers adopted strategies of co-firing coal fired power plants with biomass. Political support for this strategy was given through the exemption of the regulatory energy tax for the biomass-fired part of electricity generation.

2010-2025:Regime increasingly adopted climate friendly energy technologies

Climate change concern became a more significant driver of regime change as carbon emissions were priced through policies of emission trading and carbon taxes. Pilot projects in emission trading in the Netherlands, UK, and Denmark served as examples for the design of a European trading scheme. The European Union also reinforced its role in international electricity trade to secure reliability of the emerging European electricity system. ICT technologies became more pervasive throughout the electricity system as it enabled online energy resources and electricity markets and fine-tuning of power plant utilisation.

In the electricity regime coal power plants started to reach the end of their life-time and new investments occurred in energy technologies that suited power and environmental demands better. The strategy of co-firing with biomass reached its limit as the rising share of biomass in the fuel mix led to high capital costs to clean exhaust gases. Coal gasification, which enabled better emission control, increased in several coal dependent countries. Especially the USA was a frontrunner, with R&D in coal gasification boosted after the September 2001 terrorist attacks intensified the strategy towards resource independence. In Europe, with stronger climate pressure, the higher efficiencies that could be reached with coal gasification in combined cycles were accompanied by strategies to reduce the carbon content. This involved projects with carbon removal and sequestration and co-gasification with biomass.

While co-combustion and co-gasification stimulated early demand for biomass, later biomass gasification technology became more prominent. Regulations regarding emissions of CO_2, NO_x and other substances became based on the performance of the integrated gasification combined cycles, making further installation of traditional coal-fired power plants difficult. Moreover, biomass gasification became more attractive as costs of carbon removal were becoming a heavier burden for coal power plants.

In the Netherlands the number of households purchasing green electricity steadily grew from 10% in 2000 to 40% in 2005 and 75% in 2015. Its price level remained competitive as cost reduction of biomass and wind energy offset the reduction in feed-in premiums. The introduction of an European carbon tax, and the exemption of users of green electricity for this tax especially stimulated the number of companies using green electricity. This also provided momentum for industries to invest in and buy renewable energy. Green electricity from foreign sources grew as Dutch growth of renewable energy was insufficient. This gap closed as more wind farms and integrated gasification combined cycle power plants were constructed to replace power plants from the 1980s.

A relatively new niche development involved hydrogen production from gas, with hydrogen mixed in the gas network and CO_2 removed and either used in horticulture or sequestrated. Also conversion from gas to hydrogen and carbon black was initiated in demonstration projects, with the carbon reused in the tire industry, as it was thus able to improve its carbon profile. Hydrogen was also used for first mobile applications of hydrogen fuel cells. Another niche for hydrogen powered fuel cells concerned data processing stations that needed very reliable power that could be served by fuel cells that additionally are quiet, clean without the need for a strong grid. The growth potential of these niche market led power equipment sector to further develop and market the combined fuel cell and microturbine that with its very high electric efficiency and low emissions was very attractive in several fast growing niche markets such as back-up systems and ICT concentrated demand. The system was especially suited for power supply to areas where power demand was high and heat demand low.

2025-2050: Regime shift to international renewable electricity generation

The process of European unification continued and political power increasingly shifted to the European level. Authority over high voltage grids shifted from the national to the European level and the reliability of electricity supply was guaranteed through European law, rules and agreements.

At the regime level in the Netherlands, coal was only utilised in a gasification plant in the Rijnmond area, with the CO_2 re-used in other processes, such as in horticulture. In Europe the number of coal power plants was dropping because of the costs of CO_2 removal and the difficulty, also due to societal opposition, of finding proper locations for carbon sequestration. With a significant price on carbon emissions, investments in integrated gasification combined cycles started to outrun those in combined cycle gas turbines as they combined high efficiency with an ability to deploy various feedstocks and produce multiple products. Coalitions between energy companies and agricultural and chemical companies emerged to bundle expertise regarding biomass utilisation, electricity marketing and chemical production and marketing. Hydrogen, as one of its products, was utilised increasingly for mobile applications. Global use of biomass as an electricity generation source increased rapidly and spurred trade in various waste and biomass products. Several developing countries shifted part of their commodity production towards biomass crops that guaranteed better income than traditional crops. ICT played a role in facilitating on-line exchanges of electricity and of resources for electricity generation such as biomass and hydrogen.

After production of several thousand units of hybrid microturbine/fuel cell systems lowered their costs, power equipment producers started to produce larger scale units in the megawatt range because these enabled them to reduce costs even further and to tap other than niche markets. The systems began to compete effectively with combined cycle gas turbines especially for peak and medium loads. While initially the hybrid fuel cell/gas turbine systems were powered by hydrogen through gas reforming, they increasingly used direct hydrogen.

One source for hydrogen were offshore wind farms that produced hydrogen from surplus electricity at low demand periods. Combined production of power and hydrogen gained momentum as it solved both the problems of discontinuity and storage. Utilisation of ICT also enabled better anticipation of discontinuous resources such as photovoltaic and wind power, and thus enabled better overall control of the international electricity regime. Expectations regarding large-scale solar power increased as further strengthening of the grid, long distance transport at higher voltage, and improvement of cable and conduction technologies, led to reduction of transport losses and made transport at longer distances possible. Solar hydrogen systems were developed in Southern regions (Europe and Africa) as they served local hydrogen need and produced power for the international grid. In 2050, then, electricity demand in the Netherlands was met half by national power production with several highly efficient combined cycles based on inputs of gas, biomass and coal (with CO_2 removal) and offshore wind-hydrogen systems, leading to a halving of CO_2 emissions compared to the 1990 level. The other half was met by import of electricity based on combined cycles, offshore wind farms, solar hydrogen systems and hydropower.

7.5.3 Scenario 2: Towards Distributed Generation

2000-2010: Diverging actor strategies in the electricity regime

Changing user preferences facilitated by liberalisation induced increasing divergence in strategies of mainly international operating electricity producers and more national focussed energy distribution companies. Producers supplied cheap base load electricity by full utilisation of their large-scale power plants based on coal, oil, gas or nuclear energy. Distributors were more focussed on customers with smaller electricity demand, such as households and small firms. They were attracting customers mainly by highlighting the specificity of their product and service. Distributors aimed to further expand market niches such as industrial combined heat and power production, in collaboration with industrial actors, and they further explored technological niches such as micropower in coalition with gas utilities and electric equipment producers. Gas utilities were involved to expand the market of gas relative to central produced electricity. Several industries were involved because they needed electricity in combination with high quality heat that could be provided by microturbines. Projects with micropower for several households were supported by coalitions involved in the development of energy-efficient housing districts. The Dutch world-wide fund for nature (WWF) had developed a set of design criteria that were used in several housing projects by project developers, construction companies and municipalities. They explored the potential of further improving energy efficiency in houses by installing these micropower systems. Potential buyers were not scared away by the relatively small additional costs also because of the continuing housing scarcity, while some leading edge buyers were specifically attracted by the green profile of the houses.

The projects induced further experiments with local generation systems because several problems were encountered. Distributors had to solve problems of increasing two-way electricity flows in the local low voltage networks as these networks were designed to carry flows from central production units to users. The projects did not discern between the different heat and power demand profiles of users, leading to surplus heat production that needed to be stored. Power equipment producers began to work on designs for micropower systems with different heat-power ratios, while distributors in collaboration with producers of domestic appliances began to focus on smart appliances that could be switched on and off at the most feasible periods. As growth of electricity demand was rather concentrated, such as in areas with many ICT companies, the capacity of the grid was insufficient to serve this power demand. This led to collaboration of ICT companies and energy distributors to develop local systems that were able to serve high electricity demand and a high level of reliability.

2010-2025: Decentral combined heat and power production and micropower gained momentum

Climate change gained priority as the Netherlands had been unable to realise the Kyoto targets and Dutch government aimed to intensify its climate policy. The policy to exempt combined heat and power production partly from the regulatory energy tax came into operation, while the regulatory energy tax was now also applicable for large energy users. In the electricity regime central producers were faced with increasingly obsolete power plants that needed replacement. The relative share of central power generation continued to fall as various energy technologies provided opportunities to produce power efficiently locally.

At the niche level, leading edge companies followed examples in the USA and installed fuel cell stacks to secure their electricity supply. Several users needed more reliable power delivery for on-line financial transactions, exchanges and ICT operations. These companies installed local power back up that could handle short black outs. Also electricity contracts were settled between ICT, financial companies and energy companies that combined high reliability with high liability, and energy companies installed reliable local capacity with fuel cells for these companies.

Microturbines became more widespread as the coalition of energy distributors and gas utilities spread the application of combined heat and power systems to smaller companies, neighbourhoods and households. In several projects users were involved in the design phase of these houses to improve the balance between individual demand and the micropower system installed. Smart electrical equipment was used to improve utilisation. Leading edge users were able to effectively reduce their energy costs. This led to more users wanting to be involved in the early stage of the housing project. The high energy efficiency of these houses also led to sharpened energy performance standards in energy and housing policy. After installation companies gained experience with the design and installation of micropower in new housing districts they became convinced of its potential to replace conventional heating systems in existing houses. Users became increasingly accustomed to the use of micropower as it slowly became available in companies that provided household equipment. Marketing campaigns convinced customers of the economic and environmental benefits.

The rise of micropower for neighbourhoods and of more reliable local power supply led energy distributors to focus on the design and management of local electricity networks. In these market niches the role of energy distributors shifted towards managing local electricity flows. Until then, development of photovoltaics and wind power had been relatively independent of the development towards micropower. This started to change, as further progress was necessary to tackle the climate problem. Energy distributors played a central role in the emergence of local systems with combined use of fuel cells, photovoltaics in urban areas and wind plus photovoltaics in rural areas. WWF now aimed for housing districts that were emission free and used renewable sources for hydrogen production. The fuel cells in the cars that used hydrogen both served as a source for mobile power and for stationary power in the districts. Especially Greenpeace had been involved in getting these cars to the market in collaboration with car companies. The systems made balanced use of renewable energy production from photovoltaics, wind and biomass, and use hydrogen as an important intermediary resource. Photovoltaics and wind could either produce electricity for the households, or, in periods that power demand was low, hydrogen through electrolysis for the fuel cell.

2025-2050: Regime transformation towards distributed generation

Gas was still exploited as a resource for the production of hydrogen but its share in power generation was falling. Alternative options for the production of hydrogen steadily increased their share, such as hydrogen from biomass sources, wind energy and solar energy. Investments in power generation virtually all took place in flexible power systems that offered power close to the customers and were based on sources varying from wind and sun, to biomass and hydrogen. The systems were designed for specific local or regional demand for electricity, with connections to specific industrial users, commercial users and neighbourhoods. Also micropower systems continued to take a significant share of the power market. Investment in central capacity was absent in this period, although some larger power plants were built related to specific electricity and heat demand of industrial users.

In 2050, around 25% of electricity generation capacity was handled by relatively autonomous distributed generation systems. This emerged through the connection of previously independent small scale power generating technologies in local systems, facilitated by on-line monitoring and power management. Newly built neighbourhoods became self supportive for power generation while existing neighbourhoods increased their share of local produced power. This was stimulated by new legislation that prohibited the construction of housing areas that drew external power. Standards were developed to increase the share of local produced power in existing houses. Apart from wind and photovoltaic power, also locally produced biomass was becoming part of a local cycle of power and hydrogen production. Another 50 % of electricity generation was provided by decentral systems with a connection to the central grid. Around 25% was provided by central power plants that were not connected to specific users. Overall this resulted in a halving of CO_2 emissions compared to the 1990 level.

7.6 The value of STSc for transition policy in the electricity domain

We can use the two scenarios to evaluate current policies, and come up with strategic recommendations. Ongoing dynamics in the current electricity system offer starting points for two diverging transition paths, which are both plausible. It would be wise to develop policies, which are robust in the sense that they hold strength and relevance in both scenarios. Based on the two scenarios we draw two main policy recommendations to support a transition to a sustainable electricity system.

1) Avoid lock-in to existing design; support the built up of alternative infrastructures

A significant part of current government efforts is focussed on the path of large-scale renewable energy development, especially large-scale wind energy and the development of biomass applications. While the first scenario shows the promise of this path, a sole focus on large-scale integration has the risk of locking out other promising routes. This is unwise because there is much uncertainty whether large-scale integration will succeed. Factors that contribute to uncertainty are the shaky path of European convergence, problems of spatial integration and societal opposition, and the difficulty to integrate the various technologies into a reliable system. It is therefore sensible to invest also in other promising routes, such as distributed generation. It would be a fail-safe strategy to invest more effort in exploring other routes, rather than betting on one horse. The scenarios show that most of the promising niches do not easily adapt to the central station electricity model and have other kinds of systems and infrastructure requirements. Hence, there is a need to build up experience with alternative infrastructures, such as those for biomass, hydrogen, and local microgrids. Real-life experiments are a good way to do this, also enabling further refinement of future visions on the basis of concrete learning experiences.

2) Exploit linkage potential of niche technologies and resources

Current policies focus too much on individual technologies, and do not look at interesting combinations of technologies. This strategy is risky, because individual technologies may be unable to break out, because of specific constraints (such as wind, photovoltaic power and its intermittent character). The scenarios give insight in the potential of certain technologies and resources to act as stepping-stones or linkages in the changeover from fossil fuel based technologies to renewable sources. Fuel cells, for instance, are flexible in terms of energy resources (gas, hydrogen, (m)ethanol), and can play a role in energy storage. They can have value as a complementary technology for gas turbines, photovoltaic power, wind power, as well as biomass. Another example is the importance of gas as an energy source that can bridge the development from traditional technologies to emerging niche technologies and can create linkages between alternative designs. Combined heat-and-power production and its micro forms can pave the way for experiments with fuel cells. Gasification technology can provide a stepping-stone for further integration of the biomass niche into the regime. Moreover after initial use of gas as a power resource it has the potential in a subsequent step to shift towards production of hydrogen. In sum, the scenarios point to interesting linkages between niches.

7.7 Conclusion

In comparison to other scenario methods, the STSc tool has two strong features:

- The tool is based on a scientific theory on transitions. The patterns and mechanisms used in the tool provide an insight in *why* certain linkages and developments occur. This renders better clues for policy intervention than more deterministic methods.
- The tool not only pays attention to *future end states* but also to transition *paths*. This does not take the form of simple diffusion paths. The paper showed that the tool can lead to scenarios in which a transition emerges, not as a *deus ex machina* but as the result of plausible linkages, actor strategies, learning processes and social interactions.

The primary aim of this chapter is to show the promise of sociotechnical scenarios as a reflexive tool for transition policy. Sociotechnical scenarios can help design more robust transition oriented policies, in the sense that these policies can contribute to multiple transition paths and do not facilitate one path while blocking others. The approach can also help select promising niches that can form the seeds for a transition and thus are good options for experimentation in the near term. In particular the STSc tool is well-suited to explore how *combinations* of niches may open up different pathways. Transition policy should not just look at individual technologies, but also at processes of hybridisation and linkages between technologies and specific user preferences.

The STSc tool is not an automaton that provides a detailed prescription of instruments. We characterize STSc as a 'tool' rather than as a 'method'. The use of a tool requires skills on the part of the user, while a method refers to a sequence of steps that automatically lead to the end result. STSc is a tool, because it requires at least two kinds of skills: empirical knowledge of the relevant domain and theoretical sensitivity regarding the co-evolution of technology and society. Maybe this hampers the transfer of the tool to others. But mindful use of the tool may also lead to more interesting outcomes.

As a weakness, the tool in its present shape is that it is not well suited to compute the effects of (combinations of) policy instruments. For instance, it does not render suggestions for the exact level of eco-tax, adoption subsidies etc. Other methods may be better suited for that (e.g. computer models). This means that sociotechnical scenarios do not replace other methods, but provide an additional tool to the arsenal of future exploration.

Chapter 8

Conclusions

8.1 Introduction

The main purpose of this thesis is to gain understanding in the way the interaction between technological and institutional changes may offset processes towards systems change, and the way these processes may be directed towards sustainability. The preceding chapters evaluated change processes within the electricity system in the past thirty years and explored potential transition paths. This chapter presents the main conclusions.

After discussing several relevant theoretical perspectives in chapter two a conceptual framework was developed in chapter three that centres around the idea that the sociotechnical system for electricity provision and use, and its institutional arrangements (modes of production, coordination, and provision), is embedded in four broader institutional arrangements that coordinate:

- the way knowledge is generated, directed, distributed and used;
- the way the system is regulated and legitimated in a political sense;
- the way the system serves its function in the economic system; and,
- the way the system provides a societal function and maintains its legitimacy.

Chapter four showed that initial practices in the emerging electricity system at the end of the nineteenth century were rather divergent in terms of technological and organisational forms. A particular practice based on Edison’s central station model gained dominance as a network of actors was successful in propagating their interpretation of the electricity system and structuring the configurations of broader institutional arrangements that were emerging according to this interpretation, with the acceptance of the central station model and the principle of natural monopoly as central elements. In theoretical terms this process was characterised as institutionalisation, with gaining and maintaining legitimacy as a principal mechanism in the process. It was asserted that dominant practices organised in sociotechnical systems gain stability as a certain ‘institutional logics’, defined as a set of socially constructed assumptions, values, and beliefs, becomes prevalent. In the early electricity system the central station model and its ‘growth dynamics’ provided momentum internally and legitimacy externally. Growing electricity consumption became equated to progress, the grid became taken for granted in order to realise availability (initially), reliability (later on) and allocative efficiency (currently), and production became equated to ever larger power stations. This set-up of the system was the starting point for the analysis of a range of alternative practices and paths that were developed in the past decades.

8.2 Evaluation of alternative paths in the electricity system

In chapter four the emergence – over the past decades – of a set of alternative practices was evaluated. This was done against the backdrop of the existing sociotechnical system for electricity and its established modes of production, coordination, and provision. A first aspect under evaluation was the extent to what the emerging practice diverged from these established modes. Table 8.1 provides an overview and illustrates how the two paths that diverged least from the existing institutional arrangements were most successful as they did not require alteration of the existing design of the system and its underlying principles (see 4.2: 75). Nevertheless, factors explaining their success significantly differ, as hybridisation of gas and steam turbines was driven by international developments in and experiences with gas turbines, while the shift from coal to gas was driven by the formation of a national institutional framework for natural gas exploitation and application. In fact, the discovery of the huge gas fields in the North of the Netherlands and the institutional framework for its exploitation changed the whole setting of the Dutch economic system and society, triggering not only a changeover to natural gas for power production, heating systems, and cooking, but also a shift towards energy-intensive sectors such as chemicals and horticulture. The case also illustrates a more fundamental aspect of electricity supply in the Netherlands: government impact on the nature of resource use in the electricity sector has been consistently high since the institutional framework for gas emerged. National gas policy directly influenced the power sector’s resources shift to gas, from gas to oil and back to coal after the oil crises, and again to gas as part of the industrial policy for cogeneration.

The shift to gas facilitated the introduction of the gas turbine, which was first installed in industries and later in the electricity sector. Hybridisation of gas and steam turbines was furthermore stimulated by the increasing attention towards energy efficiency and energy saving offset by the energy crises in the 1970s. But most importantly, the introduction of the gas turbine was driven by its usefulness to serve peak loads (and its better performance relative to competitive components such as diesel engines) and thus improving the load factor of larger power plants.

Table 8.1 Assessment of paths taken in the electricity system

Path taken	**Relative success**	**Diver-gence**	**Nature of change due to new practice**
Shift from coal to gas	++	Low	Resource change requiring some adaptation of key components (turbines)
The nuclear route	-	Medium	Key technological change involving alteration of mode of production
Hybridisation of gas and steam turbines	++	Low	Technological component added to the system requiring some fine-tuning in mode of production
Coal gasification	-/+	Medium	Key technological change involving alteration of mode of production
Distant heating	+/-	Medium	Significant change in mode of provision and infrastructure as heat is distributed to users
Decentral cogeneration	+	High	Major alteration of the design of the system, local co-production of heat and electricity
Wind power	-/+	High	Key technological change involving significant changes in mode of production and coordination
Solar power	-/+	High	Key technological change involving significant changes in mode of production and coordination
Biomass	+/-	Medium	Key logistical change of resource use and supply, alteration and adaptation of key technologies
Green electricity	+	High	Key change in mode of provision in combination with varying technological changes

The pattern of breakthrough of the gas turbine serves as a relevant example of the way a transition path may unfold. The basic pattern is that of changing path dependence from within. The first step involved creating a symbiosis with the existing system and its dominant path. The introduction of the gas turbine as a new element within the system was successful due to its ability to serve a specific functional role in an existing configuration with the result of improvement of overall performance of the system. This also facilitated the built-up of experience, skills and competence with regard to gas turbine technology and applications. The second step involved extending the function of the gas turbine within the system. As international experience with the application of the gas turbine within the power sector grew, initial experimental hybridisation of gas and steam turbines made clear that such a set-up could significantly increase efficiency. A third step involved expanding the role of the gas turbine at the expense of the steam turbine. Further learning by using led to a shift in the position of the gas turbine from a supplementary component to the principal element of the set-up and combined cycle gas turbines gained dominancy in power stations during the 1990s. Domestic energy policies had relatively little to do with these developments, although gas infrastructure and the focus on energy saving certainly facilitated the process. Experiences abroad, investments of power equipment manufacturers such as General Electric and Westinghouse in turbine development were crucial. These companies also had aircraft engine divisions and were at the forefront of gas turbine technology since the Second World War (Watson, 2004: 1072). The emergence of the gas turbine and the hybridisation with steam turbines in the Netherlands, was mostly a case of integrating them into its specific setting and involved technical, organisational and operational improvements without changing the overall structure of the system.

Success of the gas turbine for power generation not only led to increasing application within the electricity system but also triggered use outside the traditional electricity sector. Gas turbine technology thus also played a crucial role in the hollowing out of the central station electricity model. It was also able to deliver high 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 sector, the strategies of distributors started to converge with those of industrial actors and decentral cogeneration increased. In combination with target group policy and environmental action plans agreed this led the distribution companies to take on the role of ‘agents of change’ after 1989. Initially, competition with the central producers occurred through the development of decentral cogeneration in collaboration with industry and other sectors. Later green electricity was developed as a potential market segment. Both developments were also induced by their commitment to increase efficiency and reduce CO_2-emissions. In overview then, institutional changes have been crucial for the way the rather international pattern of gas turbine development shaped specific paths of Dutch electricity production and consumption.

The role of institutional aspects has played a significant role in all paths taken in the electricity system that were analysed. Table 8.2 provides an overview. A first conclusion is that the central station electricity system and its institutional logics have proved ineffective in shaping alternative paths when actors, networks, resources, and knowledge had to be mobilised outside the realm of the existing system. The mode of governance internal to the electricity system, with its centralist orientation and closed nature, failed to produce successful development of nuclear energy, wind energy, and district heating, due to its inability to anticipate and adapt to the multi-actor and multi-level processes underlying these new practices. Processes of agenda building regarding nuclear energy took place within the circles of government and the electricity sector. Expectations regarding nuclear technology were high, nuclear energy was expected to able to meet growing electricity demand, and would fit very well in the central station electricity model. Yet, agendas for nuclear energy diverged between government (building a nuclear industry) and the electricity sector (keep technology choice in-house), while society at large was not part of the process. The belief in nuclear energy, which had developed in the electricity sector over a period of decades and had its legitimatization in securing electricity supply in convergence with economic growth, was increasingly being challenged by increasing strength of the role of alternative factors (environmental and risk concerns) and actors (from civil society).

Apart from being unable to legitimize the choice for nuclear technology the mode of governance also proved unable to help the development of another alternative, wind energy. Wind energy was developed initially solely to fit the requirements of the electricity system based on the heuristics of central station electricity such as large scale and continuity. This happened at a too early stage of its technological development when wind technology was not yet fit to meet these requirements, while actors outside the electricity sector were driven by different design criteria that proved to be more appropriate for further development of wind technologies. This suggests that dominant 'institutional logics' could not deliver appropriate strategies, modes of coordination, and learning processes, necessary to advance these technologies. Institutional changes played a central role in the implementation and acceleration of wind energy from the 1990s on. The separation between distribution and production and the uptake of decentral power generation options by distributors in competition to central producers is a core example. This was especially fostered when distributors committed to environmental goals under the new target group policy introduced with the first National Environmental Policy Plan. The development of wind power was one of the ways to reduce CO_2 emissions.

Table 8.2 Institutional aspects of paths taken in the electricity system

Path taken (success)	**Role of broader institutional arrangements**	**Match to central station institutional logics**
Shift from coal to gas (++)	New national institutional arrangement for gas production and provision negotiated between government and industry; serves as example for increasing government's grip on the electricity sector	Path serves condition of certainty of supply and reflects the large influence of government on resource use relative to the relative autonomy of the sector with regard to production and provision
The nuclear route (-)	Long built up of knowledge and political arrangements for nuclear energy; changeover to nuclear energy not taken for granted by societal groups; growth dynamics paradigm corroded by oil crises and de-legitimated by societal groups	Route is perfect fit to institutional logics of central station electricity system, large-scale orientation, long-term investments, and growth dynamics paradigm
Hybrid gas and steam turbines (++)	Gas turbine development driven by jet engine development, applied by power equipment producers; knowledge base expands in the Netherlands	Path emerges as it solves particular 'reverse salients' of the system through symbiosis of gas turbine with dominant practices
Coal gasification (-/+)	Diversification between nuclear, coal, and gas emerged as shared strategy between government and sector; gasification emerged as strong R&D priority as nuclear route stalls; political support relevant	Route is perfect fit to large-scale central station orientation; collaboration between SEP and government in funding pilot power plant important, break-up of SEP leads to stranded asset
Distant heating (+/-)	Energy saving policy and societal groups important drivers; knowledge-base limited after oil crisis	Path is initially developed as by-product of existing system, with a bias to large-scale distribution. Later projects with smaller scales were more successful
Decentral cogen (+)	Industrial policy for cogeneration and low-priced gas is relevant; industry interest diverges from electricity sector	Mismatch with central station system; alternative design driven by industry and later distributors
Wind power (-/+)	Initial failure due to top-down strategy, later more success due to institutional changes, new actors and partnerships; planning for sites remains major barrier	Initial failure of development largely because central station institutional logics were followed; recent high expectations for off-shore wind farms
Solar power (-/+)	Different knowledge base; building sector's arrangements important	Total mismatch with existing institutional logics and knowledge base
Biomass (+/-)	Acceptance of organic fraction as renewable energy (EU) and green (NL) electricity relevant ; Legitimacy of imports	Co-combustion does not require major modification in design; mainly resource supply and logistical problems
Green (+) electricity	Driven by market and client orientation of distributors and sustainability demand	Unthinkable in monopolistic organisation

The distributors initially lacked experience with small-scale physical planning and local politics, but wind capacity steadily increased as distributors gained experience and developed more appropriate (local) networks, and through the cumulative effects of subsidies, green funds and standard remuneration tariffs for wind power. The emergence of green electricity was a next milestone for the development of wind energy as domestic wind and biomass were the prime sources until liberalisation enabled large-scale imports. Acceleration of wind capacity in the past half decade was led by actors outside the electricity system as liberalisation reduced entry problems, for example through the development of beneficial rules for connection to and use of the grid. Before liberalisation took place distributors had been able to shape the conditions under which local producers could enter the grid, often resulting in relatively high barriers for those producers. Especially small private investors, independent power producers and cooperatives were able to expand their installed capacity after the liberalisation of the green electricity market in 2001. As provinces and municipalities committed more to renewable energy, capacity of wind on land grew significantly in recent years. But the largest promise is off-shore wind energy with a range of plans for wind farms of the Dutch coast, some expected to be constructed and connected to the grid by the end of 2006. High expectations regarding off-shore wind farms are shared internationally by networks involving the oil sector, off-shore sector, energy research institutes, electricity sector, power equipment producers, finance sector, governments and NGOs. International experience is growing, with off-shore wind farms in operation in Denmark and Sweden, and capacity on the North Sea expected to grow from around 600 MW in 2005 to several thousands megawatts in the coming two to three years. The Dutch government set a target for 6000 MW off-shore wind farms in 2020 and recently formulated a planning scheme for the North Sea which pointed out potentially suitable locations for off-shore wind farms. At the end of 2004 procedures for obtaining permits were formalised, leading to 78 concept initiatives by six consortia for 48 locations with a potential of 21000 MW. This large amount led the Minister of Economic Affairs in May 2005 to stop applications for the feed-in premium scheme for off-shore wind farms and biomass as it threatened to blow up the budget. Apparently, ceilings for maximum budget were not previously announced and it was not foreseen that attractive feed in premiums in combination with rising expectations of and preparations for off-shore wind farms could trigger such a potential rise in investments.

What this last example indicates is the way policy measures can reinforce ongoing dynamics. Similarly, policy measures can also dampen dynamics as in the case for solar energy, where changes in policies slowed down the growth rates of installed PV capacity dramatically. The main motivation of the Minister of Economic Affairs is that PV is not feasible, can not contribute significantly in the short term, and has no industrial priority, arguments which significantly diverged from the position of the Ministry in 1997, when strong potential of PV was emphasised. Other countries have developed rather different cycles of expectations, approaches, and policies, such as the policy of Japan, where the aim is to produce 50% of annual investments in power through PV by 2030, where capacity topped 1000 MW in 2004 with 270 MW installed in that year, and where a range of companies, mainly from the semi-conductor and electronics sector, have become top producers of PV.

The main point is to point out that expectations, approaches, and policies have a tendency to co-evolve with industrial and institutional changes. Liberalisation has introduced a short-term market orientation in the electricity sector which tends to lock-out PV. It also threatens other patterns of co-evolution for PV. New sets of linkages between the building sector, project developers and the energy sectors were created in the development and implementation of PV, leading also to the build up of alternative frames of references regarding functionalities. Also private panel owners, housing associations, and municipalities played key roles in emerging networks. Proto-institutions as pilots of promising institutional arrangements were developed and tested, with different ownership patterns for PV-panels (house-owners or energy companies) combined with different patterns of yield appropriation and control (Van Mierlo, 2002). Alternative frames of references were formed where PV is an integral part of houses, rooftops, and through its positive environmental profile, aesthetical image, and contributes to the long-term value of the house, i.e. an example of a potential transition path is unfolding. Power yields and installation costs are part of this picture but do not necessarily dominate the decision to utilise PV[1]. Yet, the decision to terminate PV subsidies and short-term promotion of PV is based on the traditional rationality of viewing and calculating PV as a means of electricity generation which is much more expensive than other forms, including competing renewable options[2]. Support for emerging institutional arrangements and cultivation of alternative frames of references will however be crucial to realise the promise of photovoltaic solar energy.

1 This emphasises the point that viewing and writing off PV as part of a 30 year investment in a house and its mortgage, gives different adoption decisions outcomes than seeing it as a short-term alternative to traditional power generation.

2 The main policy promoting PV is based on the contribution of PV to energy performance of houses, and the recent sharpened standard for new houses.

The path of coal gasification serves as another example of co-evolution. The case shows how strong the focus of energy R&D within the electricity sector was on extending specific technological and organisational forms within existing institutional frameworks. Moreover in the institutional setting of a SEP collective of monopolistic producers, R&D and investment costs could be transferred to consumers enabling huge investments such as for the Buggenum plant. In a liberalised, competitive market, these types of investments are unlikely to occur, unless expectations of projects are rather robust in terms of expected turnover, costs, reliability, and efficiency, and/or government plays a central role.

The pattern of change for biomass serves as a second relevant example of the way a transition path may unfold. Whereas in the case of the gas turbine the pattern was from symbiosis to competition, here the pattern is from competition to symbiosis. After the knowledge base for biomass options, logistics and conversion routes had developed, and waste incineration units and stand-alone biomass facilities started to compete with existing power stations mainly based on environmental considerations, coal-fired power plants developed symbiotic relations by crafting a strategy of co-combustion of coal and biomass. Important institutional changes were the acceptance of the EU of the organic fraction of waste as biomass and renewable energy, strongly advocated by the Netherlands, and the eligibility of the biomass fraction co-combusted in coal-fired power plants under green electricity schemes. Important policy changes were the agreements regarding the carbon profile of coal-fired power plants that were expected to converge towards the level of gas-fired power plants. In this pattern the incumbent power producers defend outside threats through adaptation of strategies to climate change concerns. The effect is that incumbent power producers develop expertise, knowledge and routines regarding biomass resources, use and logistics and may be better placed if more profound changes become inescapable.

8.3 Understanding momentum in the electricity system

In chapters five and six a more in-depth analysis of two remarkable processes of change in the electricity system was conducted. Here we followed more closely the way different elements became reconfigured as part of the emergence and development of the new practice.

A more detailed look at the evolution of decentral cogeneration leads to the following conclusions. First of all we need to stress the extent of change that had to take place in order to make the large uptake of cogeneration possible.

This involved changes in routines of a range of actors, radical organisational changes within the electricity sector (from supply orientation to client orientation, and from regional monopolies to market organisation, among others), and radical policy change within the departments of environmental and economic affairs (the theme and goal oriented target group policy). It involved changes in energy management routines in several adopter groups, ranging from process industries, to horticulture, to health care organisations, swimming pools, and hotels (and supported by the long term agreements on energy efficiency in a range of sectors). It also involved the emergence of a strong set of intermediaries playing a role in creating linkages between a diverse set of actors and providing information about the potential (relative advantage) of cogeneration, relating prospective adopters to earlier adopters, reducing the complexity of the decision to be taken; and playing a role in convincing potential adopters regarding the feasibility and compatibility of cogeneration within their existing production and service processes. And it involved the emergence of a good match between technological and organisational form (the joint-venture) that distributed risks and benefits and reduced transaction costs in a way beneficial to collaborating parties. Overall these change processes benefited from the improved cost conditions through fundamental changes in the rules applying for remuneration and grid connection and through continuous policy support schemes.

In overview, we contend that the emergence of decentral cogeneration is the result of a combination of reduction of legitimacy of existing institutional logics and the mobilisation of actors, networks, strategies and policies around an emerging alternative institutional logics. Crucial was the way this alternative institutional logics was build up outside the dominant actors and networks of the electricity sector, and initially was mostly a societal response and mobilisation to the oil and environmental crises. It could gain force as industrial actors, who challenged the central station orientation of the electricity sector, were mobilised, enabled by changing conditions (availability of gas and gas turbine technology), and as government developed an industrial policy favourable for industrial cogeneration. Nevertheless, growth was rather slow until the mid-eighties and only started to pick up when distributors broke the ranks of the prevailing logics in the electricity sector (triggered by institutional changes) and developed new client and environment oriented strategies that also fitted well with newly developed policy approaches. Thus an institutional logics emerged where rules regarding grid connection and tariffs were adapted in favour of decentral cogeneration, where policies were developed or intensified to stimulate cogeneration, and where networks were formed to provide information and tools regarding integrating cogeneration units in existing industries and sectors. More traditional approaches might claim that this is a typical example of converging strategies actors mobilising their power and resources to realise their interests, but our main point is that a sequence of changes has to be set in motion before it becomes cognitively clear for actors what those interests may be and how they may be realised in a different way. Moreover, also gas and electricity prices developed favourable for decentral cogeneration. Consequently the new institutional logics started to take root, and a set of assumptions, beliefs, and values became more and more taken for granted by a range of actor groups, each being able to define institutional logics as being congruent with their own motives, goals and values. For government it became the most efficient and effective way to realise energy saving and reduce carbon emissions while also increasing industrial competitiveness; for many industries it was a way to reduce costs and dependency upon conditions of power producers, improve their environmental profile and realise energy saving targets negotiated with government; NGOs saw energy saving as a step in a process towards more fundamental changes in energy production and consumption; and distributors saw it as a way to realise environmental targets and develop own production capacity relative to power producers. The essence of effective institutional logics is illustrated here: each actor group can find their own motivation and reasons to embrace a particular concept, enabling institutional arrangements to emerge, adapt and solidify according to the evolving new institutional logics. The essence is also that this is not a pure rational process in the sense that actors can exactly calculate the costs and benefits of implementing decentral cogeneration. In the case of companies, for example, most firms do not routinely assess alternatives for power generation, but do more or less routinely pay their electricity bills. This is similar to findings regarding the way companies make decisions on production processes and led to the famous statement of Porter and van der Linde (1995): companies leave hundred dollar notes lying around without even noticing them. Cleaner production projects and evaluations have confirmed this (De Bruijn and Hofman, 1998; 1999; 2000; 2002; Dieleman, 1999). Dieleman (1999) pointed at companies being ‘blinded’ for waste prevention opportunities and argued that confrontation was one way of opening up existing practices within firms. In the case of cogeneration, opening up of companies took place because they were informed about the concept and its logics by their association, by companies in their supply chain, by consultancies confronting them with the hundred euro electricity notes lying around on the floor, by intermediaries such as the Cogen office and Novem, and by media, such as newspapers, professional magazines, reporting the virtues of cogeneration. The message was almost the same from all these actors: cogeneration can be profitable for you, is easy manageable (or we can manage it for you as the distributor could say), and contributes to a better environment. After starting to take in the information, maybe finally after discussing informally with another business in a local meeting, companies may either take a look at calculation tools of the Cogen office or rely on the advice of experts. A set of regulative pressures (energy saving agreements), normative mechanisms (environmentally sound behaviour, trust of association), and cognitive mechanisms (repetition of similar messages and understanding about the way things are going to be done on our branch), start to synchronise and stepwise reaches companies with higher thresholds for adoption.

The emergence of green electricity in the energy system in the Netherlands triggered a sequence of events and changes in the Dutch electricity system. The interlocking of changes in institutional arrangements within the electricity sector and with broader political and societal structures created the foundation for the concept. The case showed that the mobilisation of actors under the right conditions can create strong drivers for change, but also underlined the difficulty to direct these driving forces in a sustainable direction towards fundamental change of systems of production and consumption. A crucial process explaining the emergence was the way institutional change within the electricity sector became aligned with institutional change in environmental policy making. The initial concept had relatively strong sustainability features, based on newly installed domestic renewable facilities, but as the concept travelled to other organisations these features became weaker and weaker. While the concept initially co-evolved with domestic sustainability policy, co-evolution with European liberalisation policy became gradually dominant, and was initiated by the rather short-sighted liberalisation of green electricity. The initially more fundamental principles still guide individual companies, but lost their leverage for the market as a whole. The success of green electricity, understood as increasing alignment between various groups of actors and their product and marketing strategies, policy strategies, and consumption behaviour, is based on the emergence and spread of a particular institutional logics which became interwoven with the new practice. The consumer as change agent was a new and catching concept perceived by various actor groups as good for the economy, policy, and society.

Overall, the way the electricity system is embedded in society has fundamentally changed. The reduction of legitimacy and credibility of the central station electricity system has initially led to de-institutionalisation of its linkages to wider fields in society. Instead a more demand-oriented electricity system biased towards cogeneration and green electricity gained legitimacy and was supported by institutional changes. The process of liberalisation however has set in motion diverging processes. On the one hand, a re-institutionalisation of the central station electricity system has taken place at a cross-national level as national electricity markets opened. This system is also deriving legitimacy based on high expectations for integration of large-scale renewable energy resources such as off-shore wind farms, co-combustion of coal-fired power plants with biomass and biomass based power plants. Even the nuclear option might re-emerge in the light of the Kyoto-protocol and long-term security of supply. On the other hand liberalisation has triggered a range of new products, services and technologies, frequently in combination with the shift towards an information society, and sometimes at rather local demand-oriented scales. Here a process towards integration of even more flexible and decentralised systems is a possibility, such as micro-cogeneration at the level of households. Along these two trends, we contend that cogeneration and green electricity are rather firmly rooted and institutionalised in the current electricity system and wider fields of society. Liberalisation has ended the highly favourable climate for cogeneration, but institutions, rules and the energy saving paradigm has stabilised its position within the electricity system and broader institutional arrangements. On the other hand, liberalisation has stimulated the market for green electricity although its sustainability profile has significantly weakened.

If we highlight the specific role of policies and policy actors in the cases of green electricity and cogeneration we argue that policy action has been too much blinded by the evolving institutional logics and its apparent success, which led to reinforcing already existing positive feedbacks in the short term, while loosing sight of opportunities to develop and maintain long-term conditions for the concepts such as to redirect the system of electricity production and consumption onto a more sustainable course. The effect of fundamental institutional change, liberalisation, has led to a redefinition of institutional logics in both cases and has been underestimated. Leverage potential in the path towards a more sustainable electricity system has not been fully exploited.

8.4 Revisiting theoretical approaches

This section reviews appropriateness of a range of theoretical approaches that were presented in chapters two and three in the light of the empirical analysis of change in the electricity system.

Rogers' diffusion of innovations

Rogers' (1995) work synthesises studies about the diffusion of innovations and has developed conceptual frameworks for understanding innovation decisions and rates of adoption of innovations. The decision to innovation is conceptualised as a process that occurs over time, consisting of a sequence of stages: knowledge, persuasion, decision, implementation, confirmation (Rogers, 1995: 162). His conceptual framework for determining the rate of adoption is based on five central factors (Rogers, 1995: 207):

– perceived attributes of innovations;
– type of innovation decision;
– communication channels;
– nature of the social system;
– extent of change agents' promotion efforts.

The main weakness of the model is that it does not take into account processes of co-evolution. Especially cases of significant misfits of innovations with existing practices, mutual adaptation of practices, institutional arrangements and the nature of the innovation are core mechanisms in its diffusion. Furthermore the model separates the decision to adopt the innovation from the whole innovation process. For most of the examples Rogers presents this may be appropriate, as it involves households and firms who previously were unaware of the potential of the innovation. This does not hold for the development of the large-scale energy innovations investigated here. For innovations that may be adopted at the level of households or firms, such as PV-panels and cogeneration units, the model can be useful once patterns of co-evolution have reached some stability. Elements such as communication channels, and degree of network interconnectedness (as part of the social system) have played a significant role in the diffusion of cogeneration, for example. Here, the role of the nature of diffusion networks - centralised or decentralised – also is relevant. Decentralised networks of diffusion have played an important role in the success of decentral cogeneration and green electricity, and in the increase of PV in the past years.

National systems of innovation

In the national systems of innovation approach the central focus is on the way innovative capacity of a country is by the nature and organisation of interactions between industry, government and knowledge organisations. One basic idea is that this institutional set-up has a rather strong imprint on the nature of learning and innovation patterns. A second idea is that this institutional set-up is rather country-specific and rooted in specific traditions of the way interactions between government, industry and knowledge are given shape. We concisely review the relevance of these two ideas for the Dutch electricity system.

The analysis of the various paths taken in the electricity system has explicitly pointed out institutional factors as the dominant explanation for success and failure. The nature of interaction between government actors, knowledge actors and the electricity sector has had a strong imprint on the type of approaches and the extent of learning. In this way this confirms the NSI approach and its conceptualisation of interaction and learning. Our analysis showed certain patterns of failure repeating, indicating that the institutional set-up is not geared towards a proper development and implementation of technology. While the NSI approach suggests that certain national path dependencies have build up, our analysis indicates that this is only part of the picture, and that also the evolution of a certain system of production and consumption, with its established modes of coordination, production and provision, leaves its imprint on the nature of this set-up. Moreover, the analysis of paths taken in the electricity system suggests how a variety of institutional arrangements influenced these paths, and in some cases co-evolved with them. In some cases, national institutional arrangements played a central role (e.g. shift to gas, and the nuclear path), in other cases it was the interplay between societal change, policy change, and changes in industrial and electricity sectors (e.g. decentral cogeneration). The picture is thus much more diffuse that the NSI approach suggests.

Multi-level transition theory

The focus of transition theory is on the way shifts of and transformation in sociotechnical systems may come about. A conceptual framework is developed based on three levels, landscape, regime and niche, and the way change processes at these three levels link up (see also chapters two and seven). The regime-level is where production and consumption systems are located, in socio-technical configuration held together by a set of semi-coherent rules that guides actors (Rip and Kemp, 1998).

Overall, the conceptualisation of systems change through the interplay of changes at multiple levels holds for all cases. The role of the regime in channelling the type of novelties that may break through has also shown relevant in the cases. For example, the necessity of connecting to the grid and its underlying rules has impacted development of small-scale renewable options. In this context, Rip and Groen (2001) argued that the grid functions as a sociotechnical buffer layer, an obligatory passage for novelties in electricity generation. Nevertheless, the role and function of the grid also co-evolves with changing patterns of electricity use and generation, as in the case of decentral cogeneration, and can shift from a constraining to an enabling factor as the architecture develops an orientation on regional and local exchange (Kling, 2002).

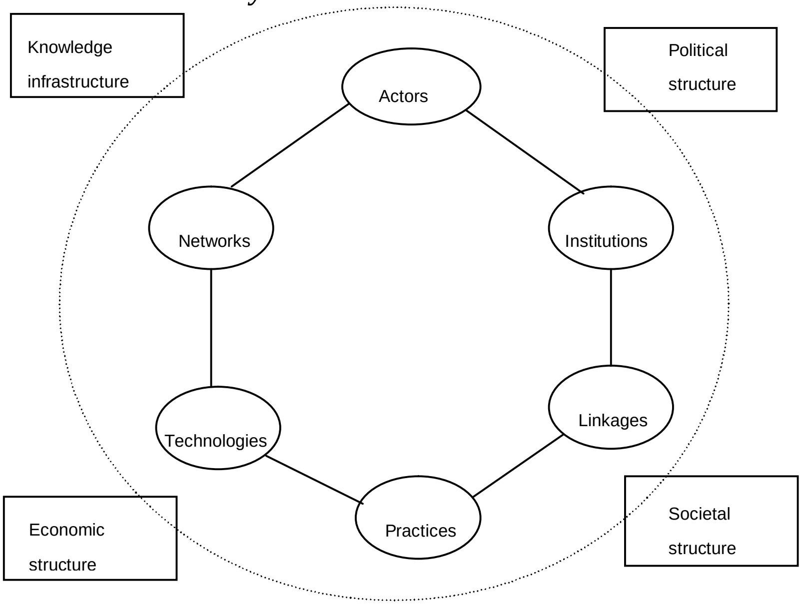
The applicability of the multi-level perspective for all cases also is an indication of its weakness. Two basic aspects form the lack of specification how and which landscape changes impact regimes and how coupling with niches take place. The model presented in this thesis aims to fill this void as it conceptualises the impact of landscape development on regimes through a translation of the four broader institutional arrangements in which regimes are embedded. If this translation synchronises between several societal substructure, impacts are likely to be high, if this does not occur outcomes will be more diffuse. Moreover, the nature of the shaping of alternative paths also co-evolves with the changes in these broader institutional arrangements, shaping alternative configurations with new functionalities such as its green profile and supported by emerging new institutional arrangements. The main point is that new concepts do not emerge solely in the context of regimes, but also in the context of changes that transcend individual regimes.

Revisiting this thesis' model

In chapter one, the overall research question asked about the nature of the interaction between institutional and technological change and the way this impacts the dynamics in the electricity system. An initial answer to this puzzle was given in chapter three where a conceptual model was introduced regarding the way sociotechnical systems are embedded in broader society, see figure 8.1. Success and failure of paths was expected to be based upon the way these paths connect with institutional arrangements of the electricity system and broader societal substructures, as earlier indicated in this chapter in Table 8.2.

The case of decentralised cogeneration can be used as an illustration. In chapter five it was shown how the promise of the alternative practice was promoted from societal circles, how knowledge regarding the practice was accumulated and spread, how broader industry became more and more involved, how policy support was developed, and the way rules were adapted to facilitate its fit with the existing system. The success was thus based on co-evolution of the practice with changing broader institutional arrangements and changes within the electricity sector's institutional arrangements (all lastpin elements in the central station electricity system were affected by the uptake of decentral cogeneration and had to adapt).

Figure 8.1 Sociotechnical systems embedded in wider societal structures



The nuclear path serves as a different kind of illustration. Here, institutional arrangements in the knowledge infrastructure were reflecting the promise and expected implementation of nuclear energy, with strong government support. Industry was also involved, and was positive about the expected low-cost electricity that could be provided through nuclear energy. However, changes in broader societal arrangements diverged from the nuclear path, and the inability to synchronise led to demise.

Both cases also illustrated the relevance of the concept of institutional logics. Nuclear technology failed because of erosion of the institutional logics it represented: growth dynamics along 'large-scale, low-cost central electricity provision enables electricity demand growth equates economic growth equates progress'. Decentral cogeneration was able to spread as an alternative institutional logics of 'doing more with less' emerged and gained momentum as it was successfully illustrated in a range of organisations and industries and embraced by a variety of actor groups.

The conclusion we draw is that the approach has promise and value for analysing and understanding dynamics in sociotechnical systems. Nevertheless, we acknowledge the rudimentary nature of the model as it needs more specification in terms of the relationships between the different elements and refinement through application in sociotechnical systems other than the Dutch electricity system.

8.5 Lessons for transition policy

The Fourth National Environmental Policy Plan published in 2001 (VROM, 2001) introduced a new way of defining environmental problems and launched the development of a new approach called transition policy. The recognition that environmental problems are firmly rooted in existing systems of production and consumption led to the conclusion that environmental policy need to be redesigned towards system innovations, a third generation environmental policy after earlier effect-oriented and integrative approaches (Grin et al., 2003). This conclusion was reached by extending existing patterns of resource use and existing policies. Existing environmental policies had proved successful in alleviating problems such as air pollution and water pollution by an increasing preventive and integrative approach, but not in reducing natural resource use. A fundamental change of course was said to be required to repair and overcome system faults responsible for problems such as loss of biodiversity, climate change, and over-exploitation of natural resources. Transitions towards more inherent sustainable sociotechnical systems in a time-scale of thirty to fifty years are required according to the document. Transition approaches for specific fields emerged, such as for energy, transport, agriculture, and biodiversity and natural resource use. The transition approach for energy was further developed by the Ministry of Economic Affairs (EZ, 2002). A number of transition routes were singled out as most promising and feasible in the Dutch context. An interactive, process-oriented policy approach was initiated in which various coalitions emerged that were working on developing more specific paths within the main transition routes and could obtain subsidies under various schemes.

We provide a short evaluation of the energy transition policy by focusing on the nature of routes proposed, the process, and the integration with conventional energy policy. Subsequently we will outline some of the lessons drawn on the basis of the previous chapters.

Transition process and routes

In the course of the development of the fourth National Environmental Policy Plan which came out in 2001, the Ministry of Economic Affairs started to develop a transition agenda for energy and the principles of the journey towards a sustainable energy supply were set out by a specific transition group at the Ministry (EZ, 2001a). The journey was presented as a search process of government and market actors. It was proposed that individual companies should take a leading role, and to ensure this government would select some large companies and ask them to join the search and transition process (EZ, 2001a: 35). Based on an earlier exploration of long-term developments in the energy system (EZ, 2000) and on consultation with a number of stakeholders also a number of promising and robust transition routes were selected: new gas, chain efficiency, green resources, and sustainable Rijnmond. Project teams were formed for these themes and in 2002 and 2003 these project groups developed general visions and a set of more specific paths through a process of workshops and interviews (EZ project group, 2002ab, 2003ab). Based on these reports discussion took place and further ideas were developed, leading to five main routes in 2004, see Table 8.3. The recent energy report of 2005 also proposed a sixth route: clean fossil (EZ, 2005).

Table 8.3 Main routes and paths in the energy transition (AER/VROM, 2004: 232)

Main routes	Recognised transition paths in 2004
Efficient and green gas	Energy saving buildings Micro and mini cogeneration Clean natural gas Green gas Energy saving horticulture
Chain efficiency	Renewal of production systems Sustainable agricultural chain Sustainable paper chain
Green resources	Biomass production Biomass conversion Biosyngas Bioplastics
Alternative motor fuels	Natural gas Biofuels
Sustainable electricity	Biomass Wind

Based on an assessment of the process and routes in the energy transition in the perspective of our analysis of paths taken in the energy system we make the following observations and suggestions.

Observation 1: Incumbents dominate the process

First, there is a relative narrow range of actors involved as reported in the initial visions and in the stakeholder consultation. There is a bias to a business approach to the energy transition, with strong representation of multinationals and energy companies, but under representation of actors such as the construction firms, housing companies, and consumer groups. This may provide some part of the explanation for the rather narrow and technological orientation of most of the proposed routes, because homogeneous networks are much more unlikely to produce ‘out of the box’ ideas. Moreover, the strong focus on incumbent companies should be assessed critically as many have pointed out how difficult it is for incumbents to deliver more radical innovations (Henderson and Clark, 1990; Utterback, 1994; Christensen, 1997). Especially new start-ups, small firms, and outsiders are found to play a pivotal role in studies of radical innovation and systems change (Van de Poel, 1998, 2000; Geels, 2002). Incumbents are sometimes able to provide new products and markets, but evidence shows that it is often small, creative, new entities and networks developing new practices that provide the seeds for new sociotechnical systems. These insights have led to a whole body of research focussing on specific management approaches to radical innovation because established management approaches for regular innovations ('evaluation routines') may even be detrimental to radical innovations (Christensen, 1997; McDermott and O'Connor, 2002; Jolivet et al, 2002).

Suggestion 1: Broaden networks and perspectives

The cases of green electricity and decentral cogeneration illustrated that alternative organisational forms, new networks, and alternative institutional arrangements can be crucial in advancing alternative practices. The inclusion of incumbent energy companies in those change processes could take place as their frames of reference and perceptions of the nature of problems and solutions shifted. We do therefore not suggest that the involved actors and proposed paths do not hold promise, but we argue for the value of involving other actors and networks exhibiting less lock-in to existing energy paths and its institutional logics.

To also adopt a constructive stance therefore two suggestions are made. One proposal is to develop a transition route around actors and networks with initial exclusion of incumbents. A possibility is to focus on ways to integrated developments in information and communication technologies (ICT) with alternative energy systems. ICT plays a role in alternative metering and control systems for energy users, and on the other hand the expansion of ICT companies, networks and use also demands new forms (quality) of energy provision. Another proposal is the development of a transition route from the user perspective. In the relative successful cases of green electricity and decentral cogeneration the role of users and a strong demand orientation played an important role. The relevance lies also in the nature of the dynamics involved in such a user oriented approach which can initiate a rather rapid take-off once an effective new practice, broad patterns of mobilisation, and catching institutional logics have materialised.

Observation 2: Consensus oriented approach to vision building

A further observation concerns the implicit focus on developing shared visions. But there may be an inherent paradox in a consensus approach to transitions. Radically new concepts that form the basis for transitions are generally not produced in that way. Think about Spence Silver who discovered the weak glue used for Post-it Notes, and who was explicitly ordered by his company that the rejection of further funding of his invention (or mistake as the company called it) was final (section 2.4.2 and Garud and Karnoe, 2001: 15). And about Kees Wiechers[3] who invented the concept green electricity, but found that almost no-one in his company believed in it. And about Eric-Jan Tuininga[4] who challenged the nuclear route, and in a 1977 televised debate, found that his opponent who defended the nuclear route had expected Tuininga to defend coal as an alternative and was totally taken by surprise when energy saving and cogeneration was proposed. What these examples and many other new concepts that were initiated have in common is that they are born out of alternative frames of reference, with only a few people initially believing in and committing to the new concept. The relative successful cases of decentral cogeneration and green electricity suggest that it is not necessarily about developing a shared vision but about developing an alternative vision and mobilising actors along the way as initial alternative practices gain strength.

Suggestion 2: Provide space for alternative frames of reference

The observation shows the importance to provide space for alternative, out of the box, thinking. One way to facilitate this is the development of arenas and settings in which actors are forced to make their underlying assumptions, beliefs and values explicit. Deliberative policy analysis is a useful tool in this respect (Hisschemöller et al., 2002; Hoppe and Peterse, 1998; Grin et al., 2004).

Observation 3: Limited attention for co-evolution of innovation and institutional change

Finally we want to stress that transition paths are shaped through the emergence and formation of alternative institutional arrangements, implying new combinations of technological and organisational forms connected to new patterns of interaction and coordination between actors. Also the main dynamics in the electricity system in the past decades is based on emergence and expansion of alternative institutional arrangements for green electricity

3 Based on personal communication with Kees Wiechers, April 2005.
4 Based on personal communication with Eric-Jan Tuininga, June 2005.

and decentral cogeneration. Instead of a focus on foremost technological paths the focus should also be on the way to provoke, support and further promising institutional arrangements.

Suggestion 3: Support promising emerging institutional arrangements

Support systems could be broadened through support for alternative concepts and associated institutional arrangements. Current examples are the development of a certification system for sustainable biomass trade (Junginger and Faaij, 2005); experiments with distributed generation models (Cogen, 1999; Hofman and Marquart, 2001: 166); and the development of local sustainable energy boards.

8.6 Epilogue: transition to a sustainable electricity system

This final section comes back to the introduction of this book where we described different approaches to the way systems change towards sustainability may unfold. The five approaches identified were the engineering approach, business approach, cultural approach, technological approach and governance approach. We proposed that elements from all approaches need to be combined for the transition to sustainability. Two final questions then leave their mark. A first question is whether we see integration of the various approaches in the unfolding paths and policies in the electricity system; and a second question is whether these approaches and their integration are specific to the electricity system of production and consumption or part of more broad societal processes of change.

We suggest that policy and paths in the electricity system are currently dominated by the technological and business approaches and a limited governance approach. The focus on technology is visible in the way certain technological options have been advanced lack consideration of the process of embedding in society and appropriate institutional frameworks for this process. The focus has mostly been on improving economic and technological characteristics of technological options, and much less on the way existing rules were hampering their advance, the way these options represented certain values and also threatened existing ones, and the way these options involved whole new sets of interactions between a variety of actors, including users. The relative success cases of green electricity and decentral cogeneration showed paths characterised by the formation of new networks and linkages, the set-up of alternative institutional arrangements shaped to the specifics of the innovative concept, and patterns of imitation, diffusion and institution building. The essence of their rapid spread was how its institutional logics was based on an alternative design, represented values congruent with those of a range of actor groups and integrating environment and economy. These cases can thus serve as exemplars for the way the different approaches may be integrated, but also indicate that these do not necessarily represent paths to sustainability, as the corrosion of the 'sustainability value' in the process showed.

The governance approach as represented by the Kyoto-protocol, is rather restricted in its character as it provides 'simple' graduated ruler guidelines and regulations for reducing greenhouse gases. An important effect has been the short-term adaptation and optimisation of electricity systems to increase efficiency and reduce carbon emissions, but a wide gap is still visible with the much more far-reaching long-term goals. We contend that reaching those long-term goals is not only about developing appropriate energy technologies but also about broadening the perspective to a sustainable path for society, as it is difficult to perceive a sustainable electricity system in an unsustainable society.

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Innovatie en institutionele verandering: De transitie naar een duurzaam elektriciteitssysteem

Summary in Dutch / Samenvatting

De aanwezigheid en beschikbaarheid van elektriciteit is alom geaccepteerd als een gegeven in onze maatschappij. Veel aspecten van onze huidige levensstijl en levensstandaard zijn gebaseerd op toepassingen van elektriciteit. Er zijn echter ook nadelen verbonden aan deze verwevenheid van elektriciteit in de maatschappij. Er is een totale afhankelijkheid van fossiele brandstoffen ontstaan in met name energie- en transportsystemen. Dit heeft geleid tot het mondiale probleem van klimaatverandering die een bedreiging vormt voor fundamentele aspecten van ecosystemen en samenlevingen in de komende decennia. De oplossing van dit probleem vergt zowel fundamentele veranderingen in systemen van productie en consumptie als in vormen van 'governance' van lokaal tot mondiaal.

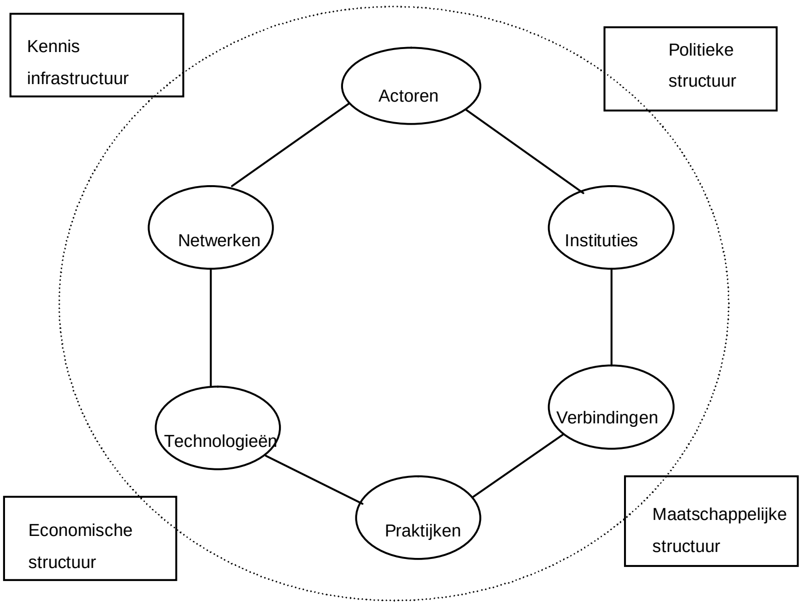
Een belangrijk uitgangspunt van dit proefschrift is dat er een sterke samenhang bestaat tussen deze twee aspecten van de oplossing. Het belangrijkste doel is daarom meer inzicht te verkrijgen in de wijze waarop de interactie tussen innovatie en institutionele verandering kan leiden tot een proces van systeemverandering, en de wijze waarop dit proces in een duurzame richting gebogen kan worden. Het empirische werk in dit proefschrift heeft betrekking op het elektriciteitssysteem.

Hoofdstuk twee van het proefschrift geeft een overzicht van theoretische perspectieven die relevant zijn voor de analyse van systeemverandering. Een eerste conclusie is een toenemende mate van integratie van institutionele aspecten zichtbaar is in innovatiegerichte theorieën. In het bijzonder voor het begrijpen van systeemverandering richt de analyse zich op de rol van veranderende interactiepatronen tussen actoren en veranderende regelsystemen in wisselwerking met technologische verandering (co-evolutie). Een tweede conclusie is dat institutionele theorieën een belangrijke bijdrage kunnen leveren aan de conceptualisering van systeemverandering als een proces van co-evolutie van institutionele en technologische verandering. In hoofdstuk drie is dit verder uitgewerkt in een analytisch kader dat richting geeft aan de empirische hoofdstukken van het proefschrift. Hierbinnen wordt een sociotechnisch systeem, zoals het systeem van elektriciteitsproductie, distributie en gebruik, opgevat als een set van institutionele arrangementen voor een bepaalde wijze van productie, coördinatie en provisie die ingebed zijn binnen een aantal bredere institutionele arrangementen voor de coördinatie van:

- de wijze waarop kennis waarop gegenereerd, gericht, gedistribueerd en gebruikt;
- de wijze waarop het systeem wordt gereguleerd en politiek gezien gelegitimeerd;
- de wijze waarop het systeem een economische functie vervult; en,
- de wijze waarop het systeem een maatschappelijke functie vervult.

In de volgende figuur wordt weergegeven hoe binnen het systeem een aantal kernelementen onderscheiden kunnen worden. Bepaalde praktijken kunnen dominant worden naarmate de verschillende elementen meer op elkaar afgestemd raken. We zien dit als een proces van institutionalisering, wat een toenemende coördinatie van activiteiten inhoudt door instituties met regulatieve, normatieve en cognitieve kenmerken.

Sociotechnisch systeem ingebed in bredere maatschappelijke structuren



Een hoge mate van institutionalisering houdt dan in dat een bepaalde praktijk als vanzelfsprekend wordt gezien, zoals de wijze waarop elk huis in Nederland is aangesloten op het elektriciteitsnet en is voorzien van stopcontacten. Alternatieve praktijken die van andere veronderstellingen uitgaan, bijvoorbeeld zelf elektriciteit opwekken, zullen dan niet worden overwogen. Daarnaast kunnen zulke geïnstitutionaliseerde praktijken verweven raken met bredere maatschappelijke structuren als ze samenhangen met een bepaalde institutionele logica, gedefinieerd als een set van sociaal geconstrueerde aannames, waarden en overtuigingen. In het vroege elektriciteitssysteem het organisatiemodel van centrale opwekking door regionale monopolies (‘central station model’) en de groeidynamiek die het voorstond zorgde voor intern momentum en externe legitimiteit. Groeiende elektriciteitsconsumptie werd geassocieerd met toenemende welvaart, het elektriciteitsnet werd vanzelfsprekend voor het realiseren van beschikbaarheid, betrouwbaarheid, en allocatieve efficiëntie, terwijl efficiëntere productie geassocieerde raakte met een steeds grotere schaal van elektriciteitscentrales en bedrijven. In het proefschrift vormt deze set-up van het systeem het uitgangspunt voor de analyse van een set van alternatieve praktijken en paden die in de afgelopen decennia zijn ontwikkeld.

In hoofdstuk vier werden een tiental alternatieve paden geanalyseerd die zijn ingeslagen door verschillende actoren binnen en buiten het elektriciteitssysteem in ruwweg de afgelopen dertig jaar, weergegeven in de tabel op de volgende pagina. De twee paden die het minst divergeerden van de bestaande institutionele arrangementen waren het meest succesvol doordat de onderliggende principes en het ontwerp van het systeem niet werden aangetast. Daarnaast pasten ze ook goed binnen de bredere institutionele structuren. De gasturbine werd geïntroduceerd in symbiose met het bestaande elektriciteitssysteem en ontwikkelde zich in een aantal stappen naar een steeds dominanter component van het systeem, waarbij uiteindelijk concurrentie plaatsvond op basis van ander principes en ontwerpcriteria door middel van decentrale warmtekrachtkoppeling. Dit proces van hybridisatie en symbiose naar concurrentie en verzelfstandiging kan gezien worden als een klassiek voorbeeld van de manier waarop een transitie zich kan voltrekken. Een ander transitie pad is van concurrentie naar symbiose zoals voor biomassa waar nadat de kennisbasis was ontwikkeld in eerste instantie vooral elektriciteitsopwekking plaatsvond via afvalverbranding en zelfstandige biomassa-installaties. Later vond symbiose met het bestaande systeem plaats door middel van het bijstoken van biomassa in kolencentrales.

Terwijl de nucleaire route ook beperkt divergeerde met de bestaande institutionele arrangementen en goed paste binnen het grootschalige centrale denken was het succes van de route relatief laag. De verklaring ligt in de afstemming met bredere structuren. Vooral maatschappelijk gezien was de nucleaire route slecht ingebed en dit leidde tot grote weerstand. Voor een tweetal routes die in hoge mate divergeerden van het bestaande systeem maar toch een grote mate van succes kenden ligt de verklaring juist in een betere afstemming met bredere institutionele arrangementen.

Boordeling van alternatieve paden in het elektriciteitssysteem

Pad	**Relatief succes**	**Diver-gentie**	**Type verandering door de nieuwe praktijk**
Overgang van kolen naar gas	++	Laag	Brandstofaanpassing die ook enige aanpassing van centrale componenten (turbines) vereist
De nucleaire route	-	Medium	Kern technologische verandering die verandering van productiewijze inhoudt
Hybridisatie van gas en stoomturbines	++	Laag	Technologisch component toegevoegd aan het systeem vereist afstemming met productiewijze
Kolen gasificatie	-/+	Medium	Key technological change involving alteration of mode of production
Stadsver-warming	+/-	Medium	Significante verandering in levering en infrastructuur door warmtedistributie naar gebruikers
Decentrale warmtekracht	+	Hoog	Major alteration of the design of the system, local co-production of heat and electricity
Windenergie	-/+	Hoog	Technologische verandering met significante verandering in productiewijze en coördinatie
Zonne-energie	-/+	Hoog	Technologische verandering met significante verandering in productiewijze en coördinatie
Biomassa	+/-	Medium	Logistieke verandering brandstof gebruik vereist verandering en aanpassing van sleuteltechnologieën
Groene elektriciteit	+	Hoog	Verandering in wijze van levering in combinatie met variërende technologische veranderingen

In hoofdstukken vijf en zes worden deze twee zeer sterk opgekomen alternatieve praktijken meer in detail onderzocht. Het betreft de sterke toename van decentrale warmtekrachtkoppeling vanaf het midden van de jaren tachtig, en de introductie en snelle opmars van groene elektriciteit binnen het elektriciteitssysteem. Voor beide geldt dat de sterke dynamiek door een combinatie van factoren tot ontwikkeling kwam, en een alternatieve institutionele logica door verscheidene actor groepen omarmd werd terwijl het bestaande systeem aan legitimiteit inboette. Dit leidde tot opeenvolgende institutionele veranderingen die de verdere ontwikkeling van de alternatieven mogelijk maakten. Een sterkere vraagoriëntatie ontwikkelde zich in het elektriciteitssysteem ten koste van het aanbodgedreven centrale model. Het proces van verdere liberalisatie heeft echter divergerende processen in gang gezet. Aan de ene kant is een re-institutionalisering van het centrale model zichtbaar die landsgrenzen overschrijdt doordat nationale elektriciteitsmarkten zich openen. Ook grootschalige duurzame energie-opwekking kan passen binnen deze ontwikkeling. Aan de andere kant heeft liberalisatie de opkomst van nieuwe producten, diensten, en technologieën tot gevolg gehad die veelal flexibel en vraaggericht van aard zijn.

Deze divergerende processen vinden ook hun weerslag in hoofdstuk zeven waar een verkenning van toekomstige transitiepaden plaatsvindt. Belangrijkste doelen zijn het ontwikkelen van een methode die meer aansluit bij de dynamiek en complexiteit van transitieprocessen en het leveren van een bijdrage aan transitiebeleid. Geconcludeerd wordt dat het huidige energiebeleid vooral inzet op de grootschalige route en daarmee de kansen van nieuwe veelbelovende combinaties van technologieën, diensten en nieuwe actoren wellicht te weinig benut.

In een slothoofdstuk worden een aantal hoofdconclusies getrokken. Met betrekking tot het theoretische perspectief wordt geconcludeerd dat de institutionele component een onmisbaar onderdeel vormt van systeemverandering. Daarbij bevestigt het empirische deel van het proefschrift dat daarbij alternatieven die sterk afwijken van het bestaande systeem alleen dan kans van slagen hebben als ze gedragen worden door institutionele veranderingsprocessen in de vier structuren waarbinnen sociotechnische systemen ingebed zijn. Ook worden een aantal lessen voor transitiebeleid getrokken aan de hand van het in gang gezette beleid voor een energietransitie. Geconstateerd wordt dat de focus sterk ligt op technologische opties die het beste passen binnen het huidige systeem en het meest competitief zijn op basis van de vigerende economische criteria. Veel minder aandacht bestaat voor nieuwe concepten die uit alternatieve denkramen geboren worden en vaak een herontwerp van het elektriciteitssysteem omvatten door ontwikkeling van alternatieve institutionele arrangementen. De voorbeelden van groene elektriciteit en warmtekrachtkoppeling maakten echter duidelijk dat dit soort alternatieve concepten een dynamiek op gang kan brengen gebaseerd op een co-evolutie van technologische en institutionele verandering waarbinnen duurzaamheid sterker geïntegreerd is.

About the author

Peter S. Hofman (1963) works as senior research associate and lecturer at the University of Twente within the School of Business, Public Administration and Technology, in particular the Center for Clean Technology and Environmental Policy (www.utwente.nl/cstm). After finishing his secondary education at the Jan van Arkel Scholengemeenschap te Hardenberg (VWO-Atheneum), he studied Political Science at the University in Amsterdam where he graduated in 1989. Before joining CSTM he worked several years at the Free University of Amsterdam (Economic-Social Institute and Department of General Economics, 1989-1991) and as an environmental consultant (Cyclus Consultancy, 1992-1995). At CSTM he publishes and teaches about policy strategies to induce companies towards more environment friendly behavior both in European and Asian settings, about environmental management, and about system innovation. Research activities included a comparative study regarding the integration of environmental policy and technology policy for the European Union, pollution control and pollution prevention practices in Europe and South-East Asia, and the management of technology responses to the climate change challenge within the electricity system for the National Climate Research Program. Current research involves the application of scenario development as a tool for exploring the transition to a sustainable electricity system funded by the Dutch Scientific Council.

Industrialised societies, and especially energy and transport systems, are addicted to fossil fuels. The emergence and shape of these systems is inextricably linked to the exploitation of fossil resources such as coal, oil and gas. Apart from local and regional environmental problems, carbon emissions through fossil fuel burning have created the problem of human-induced global warming. The nature of the global warming problem is unprecedented: it threatens fundamental aspects of ecosystems and society in decades to come. The required response will be unprecedented as well: one element is that it demands fundamental transformation of existing systems of production and consumption away from its carbon base; another element is that it demands alternative forms of governance stretching from the local to the global.

This dissertation focuses on the electricity sector as a key system in the change towards a carbon-lean and sustainable society. The main purpose of this thesis is to gain understanding in the way the interaction between technological and institutional changes may offset processes towards systems change, and the way these processes may be directed towards sustainability. The focus is on explaining relative success and failure of alternative practices and paths in the Dutch electricity system. This is done against the backdrop of the existing sociotechnical system for electricity and its established modes of production, coordination and provision, and in relation to broader institutional arrangements for knowledge generation, economic exchange, policy and regulation, and societal legitimacy. Two relative successful paths are reviewed in depth: decentral cogeneration and green electricity. Both cases point at the importance of interlocking of changes in institutional arrangements in the electricity sector and broader political and societal structures to create the foundation for the alternative practices. Momentum was gained as a range of actor groups became mobilised along a newly emerging institutional logics. The cases also underlined the difficulty to maintain these logics on a sustainable path involving fundamental change of systems of production and consumption. A final chapter draws lessons for transition policy.

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