Dutch National Research Programme on Global Air Pollution and Climate Change

Electricity in Flux:
Sociotechnical Change in the Dutch Electricity System, 1970-2000

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Abstract

This report is part of a project funded by the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP) called MATRIC: Management of Technology Responses to the Climate Challenge. Central to the Matric project is the question "How to modulate the ongoing dynamics of sociotechnical change to the climate change needs?" In the project this question is answered through empirical research in three so-called technological domains: transport and mobility; electricity generation and use; and ecodesign.

Electricity in Flux, Sociotechnical Change in the Electricity System, 1970-2000 presents the results of the empirical study on electricity generation and use. The report analyses developments of the past three decades in the electricity system in the perspective of co-evolution of technological and societal development. The electricity system based on fossil-based, large-scale, technology and a relatively closed social network is changing towards a much more diverse system in terms of actors, sources and technologies. This report explains how developments in the institutional set-up, technological base, and societal preferences and problems, underlie this process of change and provide opportunities for modulation of electricity generation and use in a climate friendly direction.

Executive Summary

Introduction

This is a summary of the report 'Electricity in Flux, Sociotechnical Change in the Electricity System, 1970-2000'. This research is carried out at the Centre for Clean Technology and Environmental Policy (CSTM) of the University of Twente as part of a larger project entitled Management of Technology Responses to the Climate Challenge (MATRIC). This project is funded by the Dutch National Research Program on Global Air Pollution and Climate Change (NRP) and is a collaborative research effort between CSTM (project co-ordinator), the Centre for Studies of Science, Technology and Society and the Department of Commercial Marketing and Marketing/Strategic Management of the University of Twente, and the Maastricht Economic Research Institute on Innovation and Technology (MERIT) of the University of Maastricht. This report presents the results of an empirical study on electricity generation and use. Other reports in the project are:

- Theoretical Elaboration of the Co-evolutionary 'Technology-in-Society' Perspective; by W. Dolfsma, F. Geels, R. Kemp, E. Moors and A. Rip, August 1999.
- Dynamics of Sociotechnical Change in Transport and Mobility: Opportunities for Governance, by E. H. M. Moors and F.W. Geels, June 2001.
- Eco-efficiency in Industrial Production, by A. von Raesfeld, F. de Bakker and A. Groen, June 2001.
- Modulation of sociotechnical change as climate change challenge: Technology-oriented climate change policies in the perspective of co-evolutionary change in electricity generation and use, car-based mobility and eco-efficiency in industrial production, by M.J. Arentsen and J.W. Eberg, June 2001.

Research background and set up

The climate change impacts as well as the societal significance of electricity production have been a strong motive to select this case for in-depth analysis in Matric. Electricity generation and use clearly manifests the dilemma incorporated in the climate change problem. It is of crucial societal importance to reduce the greenhouse effects of electricity generation and consumption without reducing the quality, security and reliability of electricity supply. The project aims to contribute to the understanding of this dilemma and to recommend on possible options to cope with it. The central question of the project, similar to the one of Matric but modified for electricity generation is:

How to modulate the ongoing dynamics of sociotechnical change in electricity generation and use to the climate change needs?

This central question is answered in several steps. Chapters two and three focus on major developments in the electricity system in the last decades. They analyse how developments in the technological base, institutional base and knowledge base were all driven by guiding principles of the central station electricity model. They also explore the alternatives to the large-scale and fossil-based electricity regime that emerged in response to the efficiency and environmental demands. Chapters four and five identify and explain patterns of change in the dominant sociotechnical regime. Some of the key changes involve the hybridisation of steam turbine technology with gas turbine technology and changeover from a supply-oriented monopoly organisation to a liberalised market based organisation. Together with increasing environmental and climate concern this also impacted the niche development of alternatives to the dominant regime. Chapter six finally analyses how governance arrangements have developed in interaction with developments in the electricity regime. The chapter also evaluates government policy efforts to initiate changes in the electricity regime. A set of recommendations is developed in order to take into account the multi-actor and multi-level character of sociotechnical development in the electricity domain.

Sociotechnical change in the electricity system, 1970-2000

Startin with the early 1970's, the dominant regime developed along a pattern of *dynamic stability* until the end of the eighties. During this period, developments basically contributed to the further optimisation of the dominant regime. The system went through a period of twenty years of technical, organisational and operational improvements, without changing the overall structure of the system and the regime. Gas turbine technology has played a pivotal role in technological development from the seventies on. The use of the gas turbine for peak demands improved overall efficiency and reliability of the system. The application of hybrid forms of steam and gas turbines enabled even higher increases of efficiency, thus effectively extending the life cycle of the steam turbine which had at that time reached optimal scale. Other alternatives, such as wind technology, could not adapt to the system, were not able to serve a specific niche, and could not generate adequate electricity for base load.

However, gas turbine technology also played a crucial role in the hollowing out of the centralised electricity regime. It was also able to deliver high electric efficiencies at smaller capacities, and industries increasingly used gas turbines from the seventies on to shave peak demand and serve base loads, as well as to produce combined heat and power. When institutional change opened up the previously closed actor network of the electricity regime, the strategies of distributors converged with those of industrial actors and decentral CHP boomed. After 1989 the distribution companies have started to take on the role of 'agents of change'. Initially, competition with the central producers occured through the development of decentral cogeneration in collaboration with industry and other sectors. Later green electricity has been viewed as a potential market segment. Both developments were also induced by their commitment to increase efficiency and reduce CO_2-emissions. But also the opportunity to partly finance this through the levy from the environmental action plan has contributed to this new committment. After 1998 a divers group of actors has been involved in the production and distribution of electricity preparing to provide various electricity services to serve specific demands of several groups of customers.

Figure 1 From stability to flux in the electricity regime

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

Figure 1 gives a simplified representation of the development of the electricity regime. From 1973 the regime has gradually become less stable. Although the central station electricity system is still dominant, it is now accompanied by an increasingly varied mix of other options for electricity generation.

Corrosion of the strength of the regime took place through a number of factors:

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

Governance and sociotechnical change

Multi-level and multi-actor processes establish the course of sociotechnical change. Interaction of actors, their strategies and actions are moulded by arrangements embedded in the course of sociotechnical development. We use the term governance to refer to the way these interactions are structured. Developments in governance have considerable implications for the electricity regime. The mode of governance based on autonomy and a natural monopoly for the electricity companies which existed until 1989 matched very well the dominant design of the electricity regime: the central station electricity system. The change of mode of governance from 1989 on creates pressure on the guiding principles of the central station electricity system. Various actors grasp opportunities to generate electricity efficiently on a decentral level, also facilitated by the development of STEG technology. The process of liberalisation from 1998 on gives further opportunities for an increase of the diversity of actors within the electricity system.

Chapter 6 focuses also on government policy and derives lessons from their success and failure. Relatively unsuccessful examples of government policy are the development of nuclear energy and wind energy. Relatively successful examples are the development of CHP and green electricity. The explanation for success and failure is rooted in patterns of sociotechnical change and modes of governance visible in the electricity regime in the respective periods. We conclude that when policy incentives and goals do not run parallel with modes of governance and (specific) actor strategies the chances for success of policy intervention is low. But also when policy incentives, goals and alignment strategies are well timed, and connect to modes of governance and actor strategies, momentum can emerge especially in combination with supportive (landscape) factors. The experiences with decentral CHP from 1989 on and with green electricity in the end of the 1990's provide examples of successful strategies. In the case of decentral CHP price development of electricity and gas have also facilitated this, just as in the beginning of 2000 reverse price developments have deteriorated the outlook for decentral CHP. The emergence of green electricity can be explained through the shift in actor strategies due to a change in the mode of governance. While previous efforts in renewable energy were dominantly policy-driven, they became increasingly market-driven with the success of green electricity. A coalition of diverse actors has proven to be very effective in spreading the concept throughout the electricity system. Also policy has played a very significant role in this process by introducing the regulatory energy tax and exempting green electricity for this tax, which effectively led to a competitive price for green electricity compared to conventional electricity.

The previous examples illustrate how patterns of sociotechnical change can provide entrance points for modulation. A final paragraph of the report focuses more specifically on some of the patterns of niche and regime development in order to set the stage for suggestions to modulate sociotechnical change towards a less carbon intensive electricity system. Examples are provided to increase understanding of the dynamics and patterns of sociotechnical change that inform where opportunities exist to trigger new actor linkages and alignments which can enable the creation of new transformational paths.

Samenvatting

Dit is een samenvatting van het rapport 'Electricity in Flux, Sociotechnical Change in the Electricity System, 1970-2000. Dit onderzoek is verricht bij het Centrum voor Schone Technologie en Milieubeleid (CSTM) van de Universiteit Twente en is onderdeel van een groter project getiteld MATRIC. MATRIC, Management of Technology Responses to the Climate Challenge, is gefinancierd door het Nationale Onderzoeksprogamma Mondiale Luchtverontreiniging en Klimaatverandering. Het betreft een samenwerkingsverband tussen drie onderzoeksgroepen aan de Universiteit Twente en MERIT van de Universiteit Maastricht.
Dit rapport geeft de resultaten weer van een empirische studie naar de ontwikkeling van elektriciteitsopwekking –en gebruik. Andere rapporten in het project zijn:

- Theoretical Elaboration of the Co-evolutionary 'Technology-in-Society' Perspective; by W. Dolfsma, F. Geels, R. Kemp, E. Moors and A. Rip, August 1999.
- Dynamics of Sociotechnical Change in Transport and Mobility: Opportunities for Governance, by E. H. M. Moors and F.W. Geels, June 2001.
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Achtergrond en opzet van het onderzoek

De keuze voor een empirische studie naar elektriciteit is zowel ingegeven door het effect van elektriciteitsopwekking en gebruik op klimaatverandering als het maatschappelijke belang van elektriciteit. Hier is scherp een dilemma zichtbaar dat wordt veroorzaakt door het klimaatprobleem. Het is van cruciaal maatschappelijk belang om het broeikaseffect van elektriciteitsopwekking en gebruik te verminderen zonder de kwaliteit, veiligheid en betrouwbaarheid van de elektriciteitsvoorziening in gevaar te brengen. Dit project heeft als doel bij te dragen aan het begrip van dit dilemma en aanbevelingen aan te dragen hoe er mee om te gaan. De probleemstelling van dit project is verwant aan die van het MATRIC-project als geheel maar toegespitst op het domein van onderzoek en luidt:

Hoe kan modulering van de dynamiek van sociotechnische verandering in elektriciteitsopwekking en gebruik naar de eisen van klimaatverandering plaatsvinden?

Beantwoording van deze vraag vindt in een aantal stappen plaats. Hoofdstukken twee en drie van dit rapport richten zich op belangrijke ontwikkelingen in het elektriciteitssysteem in de afgelopen decennia. Er wordt geanalyseerd hoe ontwikkelingen in de technologische, institutionele, en kennis-infrastructuur werden geleid door de basis principes van het 'central station electricity system'. Verder worden alternatieven voor het grootschalig en fossiele elektriciteitsregime beschreven die zich aandienden als reactie op eisen van efficiëntie en milieu. Hoofdstukken vier en vijf identificeren en verklaren veranderingspatronen in het dominante sociotechnische regime. Enkele kernveranderingen betreffen de hybridisatie van stoomturbine technologie met gasturbine technologie en de verschuiving van een aanbodgerichte monopolistische organisatie naar een geliberaliseerde marktgerichte organisatie. Samen met toenemende aandacht voor milieu en klimaat beïnvloedde dit ook de niche-ontwikkeling van alternatieven voor het dominante regime. Hoofdstuk zes tenslotte analyseert de ontwikkeling van 'governance' arrangementen in samenhang met ontwikkelingen in het elektriciteitsregime. In het hoofdstuk worden tevens de inspanningen vanuit het overheidsbeleid om veranderingen in het elektriciteitsregime te initiëren geëvalueerd. Er wordt aanbevolen om in te spelen op het multi-actor en multi-level karakter van sociotechnische verandering in het elektriciteitsdomein.

Sociotechnische verandering in het elektriciteitssysteem, 1970-2000

Vanaf 1970 tot het einde van de jaren tachtig ontwikkelt het dominante regime zich volgens een patroon van dynamische stabiliteit. Gedurende deze periode droegen ontwikkelingen voornamelijk bij aan een verder optimalisatie van het dominante regime. Het systeem maakte in twintig jaar een periode van technische, organisatorische en operationele verbeteringen door, zonder dat de structuur van het systeem en regime werd aangetast. Vanaf de jaren zeventig heeft gasturbine technologie een cruciale rol in de technologische ontwikkeling gespeeld. De eerste toepassing van gasturbines vond plaats om pieken in de elektriciteitsvraag op te vangen en leidde tot verbetering van de efficiëntie en betrouwbaarheid van het systeem. Toepassing van hybride vormen van stoom- en gasturbines maakt het mogelijk om de efficientie in elektriciteitsproductie verder te verhogen en de levenscyclus van de stoomturbine, die een optimale schaal had bereikt en waar de progressie in efficiëntieverbetering stagneerde, verder te verlengen. Andere alternatieven, zoals wind technologie, waren niet in staat zich aan het systeem aan te passen, voorzagen niet in een specifieke niche, en konden niet adequaat bijdragen aan de basislast van het centrale elektriciteitssysteem.

Gasturbine technologie speelde echter ook een cruciale rol in het uithollen van het centraal georiënteerde elektriciteitsregime. Het was in staat hoge elektrische rendementen te realiseren bij kleinere schaal. Om die reden maakten industriële bedrijven vanaf de jaren zeventig in toenemende mate gebruik van gasturbines om piekvraag op te vangen, basislast te produceren en voor de productie van warmtekracht. Op het moment dat institutionele verandering het gesloten actor netwerk van het elektriciteitsregime openbrak, begonnen de strategieën van distributiebedrijven te convergeren met die van industriële actoren en ontstond een hoos in decentrale warmtekrachtkoppeling. Na 1989 profileren de distributiebedrijven zich als 'change agents' door eerst te concurreren met centrale elektriciteitsproducenten door decentrale warmtekrachtkoppeling in samenwerking met industrie en andere sectoren re realiseren. Later wordt 'groene stroom' gezien als een beloftevol marktsegment. Beide ontwikkelingen worden teven gevoed door aangegane verplichtingen voor efficiëntieverbetering en reductie van CO_2 emissies, en door de mogelijkheid dit deels te financieren door heffing ingesteld op basis van het milieuactieplan van de elektriciteitsdistributiesector. Na 1998 is een diverse groep van actoren betrokken bij de productie en distributie van elektriciteit die verscheidene diensten ontwikkelen en leveren om te voorzien in specifieke vraag van verschillende groepen consumenten. Opmerking Maarten: wat bedoel je precies met deze zin, wellicht iets specificeren

Figuur 1 geeft een versimpelde weergave van de ontwikkeling van het elektriciteitsregime. Vanaf 1973 is het regime geleidelijk minder stabiel geworden. Alhoewel het 'central station' elektriciteitsmodel nog steeds dominant is, wordt het in toenemende mate vergezeld van een gevarieerde mix van alternatieve opties voor elektriciteitsvoorziening.

Figuur 1 Van stabiliteit naar flux in het elektriciteitsregime

		1973	1979	1989	1998
Degree of regime stability	Very stable	Stable	Less stable	Less stable	Flux
Technologies	Steam turbine	Steam turbine, gas turbine (niche)	Hybrid steam turbine (STEG) / gas turbine	Niches - Decentral CHP - PV - Wind - Biomass	Increasing variety of niches - renewables - green electricity - fuel cells, microturbines
Technological configuration	Stable	Stable	Adapted with STEG	Attacked by decentral CHP	Central station electricity model shifts to EU level
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Organisation of actors	Stable	Stable	Concentration (national)	Concentration and division (national)	From public to private owned; from national to foreign ownership; new actors; new coalitions
Entrance to regime	Closed	Closed	Closed	Limited access	From limited to free access

Aantasting van de kracht van het regime vond plaats door een aantal factoren:

- Gasturbine technologie en hybride vormen met de stoomturbine die in de vroege adoptiefase het regime versterkte toen het werd geconfronteerd met een veranderende selectieomgeving door eisen op het gebied van energiebesparing en efficiëntie, en de ontwikkeling naar kleinere schaal, tastten de leidende principes van het dominante elektriciteitssysteem aan;
- Institutionele verandering (liberalisering) heeft het gesloten en centrale karakter van het dominante regime opengebroken;
- Ontwikkelingen in technologie voor warmtekrachtkoppeling samen met mogelijkheden door institutionele veranderingen en een pakket stimuleringsmaatregelen vergroten de kansen voor decentrale opwekking.
- Het dominante regime ondervindt toenemende moeilijkheden om te voldoen aan externe eisen op het gebied van emissies, efficiëntie, en klimaatverandering.

Governance en sociotechnische verandering

Multi-actor en multi-level processen bepalen het pad van sociotechnische verandering. Actoren en hun strategieën en activiteiten dragen sociotechnische veranderingen. We gebruiken de term governance om aan te geven hoe deze actoren (oud was interacties) zijn gestructureerd. Ontwikkelingen in governance hebben effect op het elektriciteitsregime. Het governance arrangement gebaseerd op autonomie en monopolistische organisatie van de elektriciteitssector dat bestond tot 1989 correspondeert goed met het dominante ontwerp van het elektriciteitsregime: het ‘central station’ elektriciteitsmodel. Vanaf 1989 leidt de verandering in governance arrangement tot druk op de leidende principes van dit model. Verschillende actoren grijpen kansen aan om elektriciteit efficiënt op decentraal niveau op te wekken, mede mogelijk gemaakt door de ontwikkeling in STEG technologie. Het proces van liberalisering geeft vanaf 1998 ruime mogelijkheden voor nieuwe actoren om het elektriciteitssysteem binnen te dringen.

Hoofdstuk zes richt zich tevens op overheidsbeleid en evalueert succes en falen. Relatieve onsuccesvolle voorbeelden van overheidsbeleid betreffen de ontwikkeling van nucleaire energie en van windenergie in de jaren zeventig. Relatief succesvolle voorbeelden zijn de ontwikkeling van decentrale warmtekrachtkoppeling en groene stroom. De verklaring voor succes en falen is geworteld in patronen van sociotechnische verandering en governance arrangementen zichtbaar in het elektriciteitsregime in de betreffende periodes. Geconcludeerd wordt dat wanneer beleidsprikkels en doelen niet parallel lopen aan governance arrangementen en (specifieke) actor strategieën de kans op succesvolle beleidsinterventie gering is. Maar wanneer beleidsprikkels, doelen en netwerkstrategieën goed getimed zijn, en aansluiten bij governance arrangementen en actor strategieën kan momentum ontstaan wanneer ook externe (landschaps)factoren meewerken. De ervaringen met decentrale warmtekrachtkoppeling vanaf 1989 en met groene stroom aan het eind van de jaren negentig zijn voorbeelden van succesvolle strategieën. De opkomst van decentrale wkk werd gefaciliteerd door de prijsontwikkeling van elektriciteit en gas, net zoals aan het begin 2000 omgekeerde prijsontwikkelingen hebben geleid tot verslechtering van het vooruitzicht voor decentrale wkk. De opkomst van groene stroom kan worden verklaard uit veranderende actor strategieën als gevolg van veranderingen in het governance arrangement. Terwijl eerdere initiatieven voor duurzame energie vooral beleidsgedreven waren, werd de markt de drijvende factor in het succes van groene stroom. Een coalitie van diverse actoren bleek effectief in het verspreiden van het concept door het gehele elektriciteitssysteem. Beleid heeft ook een belangrijke rol gespeeld in dit proces De invoering van de regulerende energiebelasting en de vrijstelling daarvan voor groene stroom leidde tot concurrerende prijzen voor groene stroom ten opzichte van traditioneel opgewekte elektriciteit.

De voorgaande voorbeelden illustreren hoe patronen van sociotechnische verandering aangrijpingspunten geven voor modulering. Een laatste paragraaf van het rapport richt zich meer specifiek op patronen van niche en regime ontwikkeling en geeft suggesties voor de modulering van sociotechnische veranderingsprocessen naar een koolstofarm elektriciteitssysteem. Er worden aanbevelingen gedaan om het begrip van de dynamiek en patronen van sociotechnische verandering te vergroten en om op basis van dit inzicht nieuwe paden te ontwikkelen die op termijn kunnen leiden tot een koolstofarme elektriciteitsvoorziening.

Contents

List of Abbreviations

AC	Alternating Current
Amolf	FOM institute for Atomic and Molecular Physics, one of the seven FOM institutes, renamed Amolf in 1966.
APX	Amsterdam Power Exchange, Trade market for Electricity, initiated in 1998.
BCN	Brandstofcel Nederland, Fuel cell the Netherlands, research institute founded by Stork and Royal Scheldegroep in 1990, with participation from ECN in 1991, on the development and commercialisation of fuel cells.
BEOP	Bureau Energie-onderzoek Projecten, Energy Research Projects Office of ECN, founded in 1977 to co-ordinate several research programs of the Ministry of Economic Affairs.
BMD	Brede Maatschappelijke Discussie, Broad Societal Discussion, from 1982 to 1984 as a means for decision making regarding the future energy supply. The BMD was specifically enacted to dampen societal concern with respect to the proposed extension of the use of nuclear energy in the Dutch energy supply.
BTG	Biomass Technology Group, initiated in 1979 at the department of chemical engineering of the University of Twente, acquired by TNO in 1997.
CE	Centre for Energy Saving and Clean Technology, independent research and consultancy institute, initiated in 1978. Developed an alternative scenario for future energy supply based on energy saving and introduction of renewables for the BMD.
CHP	Combined Heat and Power generation
CWD	Consultancy services for wind energy in developing countries, group set up in 1973/4 at the TU Eindhoven, later managed by DHV.
DC	Direct Current
Dte	Dienst uitvoering en toezicht Elektriciteitswet, Organisation for implementation and control Electricity Act 1998.
DUWIND	Delft University WINDenergy, initiated in 1999.
ECN	Energie Onderzoekcentrum Nederland, Energy Research Center the Netherlands, renamed from RCN to ECN in 1976.

EnergieNed	Federation of Energy Distributors; Since july 1999 federation for all companies playing an active part in the production, transport, trade or supply of gas, electricity or heat in the Netherlands.
FOM	Stichting Fundamenteel Onderzoek der Materie, Foundation for Fundamental Research on Matter, founded in 1946. FOM now manages the distribution of funds of NWO for physics research (around 150 million guilders annually).
GKN	NV Gemeenschappelijke Kernenergiecentrale Nederland, Collective Nuclear Power Plant the Netherlands, initiated in 1965 by the SEP and PZEM to construct the nuclear power plant in Dodewaard.
ISES	International Solar Energy Society, Dutch branch initiated in 1976
IVEM	Center for Energy and Enironmental Studies, initiated at the Royal University of Groningen in 1984.
IvW	Instituut voor Windenergie, Institute for Wind Energy, Technical University Delft, initiated in 1984.
KEMA	NV tot Keuring van Elektrotechnische Materialen, founded in 1927 by the electricity sector.
KSLA	Koninklijke Shell Laboratorium Amsterdam, Royal Dutch Shell Laboratory Amsterdam.
KV	Kilovolt
LSEO	Landelijke Stuurgroep Energieonderzoek, initiated in 1974, succeeded by REO in 1980.
MW	MegaWatt
MWe	Megawatt of electric power
MWth	Megawatt of thermal power
NEOM	Nederlandse Energie Ontwikkelings Maatschappij, Dutch Energy Development Organisation, founded in 1976.
NOVEM	Nederlandse Organisatie voor Energie en Milieu, renamed from NEOM and integrated with PEO in 1988.
NRG	Nuclear Research and Consultancy Group, an ECN-KEMA company, was established in 1998 through the merger of ECN's and KEMA's business activities in the nuclear fields. NRG provides expertise and services in support of the safe, ecologically sound and efficient use of nuclear installations and develops and applies spin-off technology for the non-nuclear

markets.

NOW — Dutch Organisation for Scientific Research, manages the funds (annual budget of around 750 million guilders) for scientific research not ear-marked to universities.

PDE — Projectbureau Duurzame Energie, Project office renewable energy, initiated in 1998. Foundation with three shareholders: Ministry of Economic Affairs (50%); SEP (25%), and EnergieNed (25%).

PEO — Projectbeheerbureau voor Energieonderzoek, Project Management office for Energy research, merger in 1984 of project management offices for energy research of ECN and TNO.

PWK — Projectbureau Warmte/Kracht, Project office Heat and Power Cogeneration.

RCN — Stichting Reactor Centrum Nederland, Foundation Reactor Center the Netherlands, initiated in 1955, renamed ECN in 1976.

REO — Raad voor het Energieonderzoek, Council for Energy Research, initiated in 1980 as follow up on LSEO, abolished in 1983.

RUG — Royal University Groningen.

SDE — Stichting Samenwerkingsverband Duurzame Energie, Collaborative initiative Renewable Energy

SEP — Samenwerkende ElektriciteitsProducenten; Co-operation of Electricity Producers, initiated in 1949.

SIGE — Samenwerkingsverband Industriële Grootafnemers van Energie (Association for Giant Industrial Customers of Energy), founded in 1979.

STW — Stichting voor Technische Wetenschappen, Foundation for Technical Sciences, initiated in 1981.

SVEN — Stichting Voorlichting Energiebesparing Nederland, Foundation Information Energy Saving the Netherlands, initiated in 1976 by the Dutch government to promote energy-efficient energy use.

TenneT — National Managing Organisation for the Electricity Network (responsible for the high voltage network, 220 and 380 kV) initiated in 1998 as a consequence of the new electricity act.

TNO — Centrale organisatie voor Toegepast Natuurwetenschappelijk Onderzoek

TUD — Technical University Delft

TUE — Technical University Eindhoven

UT	University Twente
UU	University Utrecht
VCE	Verkenningscommissie Energieonderzoek, initiated in 1996 by the ministries of OCW (Education, Culture and Science) and Economic Affairs to inform the ministries about strategic options regarding energy research.
VDEN	Vereniging van Directeuren van Elektriciteitsbedrijven in Nederland, Association of Directors of Electricity Companies in the Netherlands.
WRK	Wetenschappelijke Raad voor Kernenergie, Scientific Council for Nuclear Energy, founded in 1963 with the implementation of the Nuclear Energy Act of 1963.

1. Introduction

This report is part of a project funded by the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP) called Matric: Management of Technology Responses to the Climate Challenge. Central to the Matric project is the question "How to modulate the ongoing dynamics of sociotechnical change to the climate change needs?" In the project this question is answered through empirical research in three so-called technological domains: transport and mobility; electricity generation and use; and ecodesign. This report presents the results of electricity generation and use and this chapter introduces the project.[1]

1.1 The electricity system and the climate change problem

In modern industrial society electricity provides light, power, heat and cold. In the Netherlands electricity is predominantly used as energy source of power and light, and less used for heat and cold. Electricity has become an indispensable energy source and is of crucial interest for society. At the same time our electricity system almost completely dependent on fossil fuels. In the Dutch thermal electricity system gas oil and coal are used for electricity generation. Renewable and nuclear energy, alternatives for fossils, only have a very restricted share. The dominance of fossil fuels in electricity generation however has an important problem associated with it: the combustion of fossil fuels leads to CO_2 emissions that contribute to the problem of climate change. Society is faced with a dilemma: on the one hand electricity is of vital societal interest, but on the other hand production and consumption of electricity contributes to the problem of climate change. In the Netherlands the share of electricity generation in the total annual emissions of CO_2 was approximately 26% in 1999, and therefore the largest contributor[2] to emissions of CO_2 (ECN, 2001: 112).

For that reason, climate change policies strongly focused on the reduction of the climate change impact of electricity generation and use already from the beginning of the 1970s on. Among others, these policies included energy saving programs and the development of new generation technologies based on renewable energy resources. Despite strong emphasis on energy saving, electricity production and consumption steeply increased in the last three dec-

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[1] Our research on the electricity domain has particularly benefitted from discussions with, and comments from, Maarten Arentsen, Theo de Bruijn, and Valentina Dinica.

ades. Electricity is indispensable in the complex industrial society with a strong dependency on electricity driven equipment. The societal significance of electricity still increases, which stresses the need to relieve the climate change impact of the thermal fossil-based electricity system.

Next to extensive energy saving programs, technological innovation and improvement of generation technology have responded to the climate change impact of electricity generation. The efficiency rates of fuel conversion increased over the years and natural gas developed as the dominant fuel in Dutch power generation. Gas is generally perceived as a relatively climate sound fossil, compared to coal and oil. These innovations could not reduce CO_2 emissions of power generation. Between 1990 and 1998 the emissions steadily increased, which stresses the need to initiate much stronger changes in order to comply with the CO_2 reduction targets of the Kyoto-agreement at the minimum. One option is to increase the share of renewable-based generation technology in electricity generation. However, as the analysis of Matric shows, these technologies find strong barriers in their development and on their way to the market. These barriers not only relate to the economics (costs) of these alternative technologies. As the analysis in this report will show, the development and rise of renewable-based technologies suffered from their misfit with the functional requirements of the central station electricity system, which has been the dominant technological configuration for more than a century in electricity generation.

The climate change impact as well as the societal significance of electricity has been a strong motive to select this case for in-depth analysis in Matric. Electricity generation and use clearly manifests the dilemma incorporated in the climate change problem. It is of crucial societal importance to reduce the greenhouse effects of electricity generation and consumption without reducing the quality, security and reliability of electricity supply.

The project aims to contribute to the understanding of this dilemma and to recommend on possible options to cope with the dilemma. In particular the projects' aim was:

- To increase the knowledge regarding the sociotechnical development of the electricity system as we know it today; and
- Based on this knowledge, to recommend on strategies contributing to an acceleration of a transition towards a less carbon intensive electricity system.

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[2] The second largest contributor is industry (25%), followed by transport with 20% (ECN, 2001: p. 112).

These aims translate into several research questions that guided the analysis.

1.2 Central and operational research questions

The central question of the project, similar to the one of Matric but modified for electricity generation is:

How to modulate the ongoing dynamics of sociotechnical change in electricity generation and use to the climate change needs?

The project tackled this central question by a number of operational questions for electricity generation and use. These questions are:

1. What have been major sociotechnical changes in the Dutch electricity system between 1970 and 2000?
2. Do these changes manifest certain patterns?
3. How can the observed patterns be explained?
4. What actor strategies have influenced technological developments in the electricity system and what has been the impact of government policies in this regard?
5. What are the implications of the answers on these questions for modulation of dynamics of sociotechnical change in electricity generation and use to climate change needs?

The first question has been formulated to trace the major sociotechnical developments in Dutch electricity generation and consumption. Climate change impact has been used as a criterion for identifying relevant developments of the Dutch electricity system. For that reason this part of the analysis concentrates on developments to relieve the climate change impact of generation technology by technological innovation, on the use of alternative energy carriers, on in energy saving, and on changes in the institutional and industrial organisation of the electricity industry. Chapter three of this report answers the first research question.

The second and third research questions have been answered with the help of the analytical framework developed in Matric.[3] Matric's analytical framework holds an evolutionary per-

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3 This analytical framework has been further eleborated in Dolfsma *et al*, 1999. In the final report of Matric the conclusions of the three empirical studies are presented based on this analytical framework.

spective on processes of social and technological change and assumes co-evolution between social and technological change. The co-evolutionary approach analyses development patterns and provides for explanation of these patterns. Essentially explanatory mechanisms are the cumulative development of knowledge and self-reinforcing sociotechnical paths along which technologies develop. These paths tend to reinforce themselves because they guide and determine to a large extent the search for new technologies. This can be clarified as follows.

Our current technology strongly builds on how we have learned to invent and to develop technology in the past. These past achievements are not only visible in the technologies surrounding us today, they are also visible in scientific laws, technological principles, science and engineering practices, and search routines, as well as in the training and education of new generations of scientists and engineers. Technology builds on this knowledge that has accumulated in science, technology and in the economy. The collective memory that develops in this way is passed through history from one generation to the next, cumulatively building and developing new generations of technology, each incrementally improving the performance of its predecessor. In this way technologies build and develop their own irreversible development patterns and it is this process that focuses and narrows ("locks in") the way we search for new, better performing technologies. Thus the development of technology becomes path dependent and locked in to specific trajectories. The longer their history, the stronger their path, and the more difficult it becomes to search for new, fresh, technological solutions outside the existing technological paths. New problems, such as the climate change problem, are conceptualised in the vocabulary, knowledge, skills and routines common to the existing technological paths and regimes, in this way moulding and guiding the search for solutions. New problems are tackled with old solutions because the old solutions have proven effective in the past.

Within the co-evolutionary approach the cumulative nature of technological development is expressed in the concept technological regime. A technological regime is viewed 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 (Rip and Kemp, 1998: 338). A technological regime thus forms the context for technological change and development within specific societal domains. The co-evolutionary approach moreover assumes that at the micro-level, decisions and activities of actors and their interactions carry sociotechnical change and development. The regime on the one hand is the reference for these actor actions and interaction, which at the same time add to the further development of the regime. The relationship between actors and regime is thus mutually reinforcing.

Sociotechnical change results from the everyday activities of scientists and engineers, working in laboratories doing research and teaching students, of managers running their business and deciding on new investments, of consultancy firms advising on process and product improvements, of bank officials deciding on investment loans, and of public agencies writing policy documents, providing R&D funding or licensing firms. All these actors and their everyday decisions and activities mould and shape technology without consciously being aware of that fact. They all act in a seemingly uncoordinated way. They are motivated and guided by the economic logic of the market, the political logic of the bureaucracy or the scientific logic of the laboratory. A variety of incentives, past experiences and future expectations, motivate and influence these actors in their decisions and activities, which jointly mould and shape technological change. But these actors are not merely passively influenced; they try to shape and influence the outside world according to their own interests, in their daily activities. They develop and maintain networks with other firms, organisations or actors to increase access to and control over critical resources needed for the achievement of their specific goals and ambitions. They develop coalitions and strategic alliances to maintain and improve their resource position and to strengthen their market positions.

This analytical perspective - only briefly sketched above - guided the analysis and explanation of sociotechnical change in Dutch electricity production and consumption. Central in the analysis is the concept of regime as described earlier. At the meso-level of the regime, actors, their strategies and the dynamic of their interactions have shaped certain sociotechnical patterns of development. The analysis traced regularities in the interaction patterns of actors. The structures that guide these interactions are perceived as de facto modes of governance, which both enable and constrain the type and direction of sociotechnical development. As certain modes of governance may enable the emergence and development of a climate sound technological path, whereas other modes may constrain these kinds of developments. Our explanatory framework strongly draws on the conditional impact of governance structures on type and direction of sociotechnical change in electricity generation and consumption. In this perspective, modulation to a large extend implies to establish the “right” governance structures to enabling actors to craft a path that will be inherently climate friendly. The final section of this report holds the first building blocks for this kind of modulation strategies.

1.3 Structure of the report

Chapter two briefly sketches some core elements in the history of the Dutch electricity system. This chapter serves as background information for the further analysis in the report. Chapter three describes the sociotechnical developments in the period 1970-2000 and answers the first research question. Chapter four analysis the specific patterns of the change and development process analysed in chapter three. The chapter, therefore, answers the second research question. Chapter five provides for explanation of the traced patterns of sociotechnical development in the electricity system and will answer the third research question of the project. Finally, chapter six more specifically analysis the governance of sociotechnical change and the policies enacted in this regard. Chapter six, therefore, answers research questions four and five of the project.

2. Historical development of the Dutch electricity system

2.1 Introduction

This chapter provides a brief sketch of the development of the Dutch electricity system and serves as a background for the subsequent chapters of this report. The Dutch electricity system has evolved on the basis of the model of the central station electricity system, a model dominant in the development of electricity systems throughout the industrialised world. The principles on which the model is built are introduced in the next section. Paragraph 2.3 illuminates the way this model has evolved in its early stages in the Netherlands. Against this background later chapters will analyse in more detail developments in the Dutch electricity system for the period 1970 to 2000.

2.2 The dominant design: the central station electricity system

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

The secrets untangled by Thomas Edison and his successors enabled the construction of the central-station electricity system as we know it today. From a technological point of view a rather homogenous technology consisting of large power plants is interconnected by a system of high and low voltage wires transmitting the (transformed) electricity directly to industrial and residential consumers. Electricity production, transmission and consumption is a well integrated system consisting of a large set of interconnected technological components, most often highly complex themselves. The development of this central-station electricity system took more than a century and went through different stages:

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

The system’s optimisation at an ever increasing scale, maintaining reliability and reducing operation costs, have been ultimate drivers in the technological development of the electricity system. The basic technological principles guiding this process have been formulated in the 1920s and have not changed since then. They include:[4]

- 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.

The electricity system, build on these technological principles, is rather homogenous throughout the industrial world and the technical configurations basically differ in the mix of energy resources (fossils, hydro, nuclear, renewables) used for power generation. From a technological point of view the system is mature and rather sophisticated, and able to meet high reliability standards in general. Systems fall out is relatively rare and most often caused by exogenous circumstances such as extreme weather conditions. More than a century of societal resources have been invested in the building and development of the system, which cumulated in a scientific and engineering knowledge base accompanying current technology.

In the Netherlands the central station electricity system model guided the building and development of the national electricity system. As in other European countries the central station model became also the dominant model in the Netherlands.[5] The building and development of the system followed the principles underlying the dominant model. The next section sketches the major steps in the development of the dominant electricity model in the Netherlands.

2.3 The emergence of the system: electrification of the country

The electrification of the Netherlands began at the end of the nineteenth century with local initiatives from foremost private investors. The system thinking introduced by Thomas Edison in electricity supply gave an important impulse to this development. Following foreign developments the first initiatives were taken to construct and exploit power plants in the Netherlands. The small scale of these first electricity systems led foremost to involvement of municipal governments. The local 'energy policy' in those days consisted mainly of three related priorities: concession policy, the competition with (municipal) gas supply, and municipal revenue. Typical for period until around 1920 is the diversity of approaches. Based on local considerations, municipalities decided whether to grant applications for concessions. Applications for electricity concessions were often also considered on the extent to which

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[4] The list of principles is literally taken from Hughes (1983: 370). Hughes took the list of principles from engineering journals in the 1920s.

[5] The recently published second volume of "Techniek in Nederland in de twintigste eeuw" (Technology in the Netherlands in the Twentieth Century) focuses on energy, and includes a comprehensive overview of the main developments in the Dutch electricity system (Verbong, 2000).

electricity supply formed a threat to the municipal gas supply and its associated revenues. Especially in urban areas municipal governments exploited local gas companies with considerable revenues. The municipal distrust against the new technology decreased as its continuous progress led to growing insight regarding the advantages of electricity as a light and power source, thus giving space to new initiatives.

Increased understanding regarding the connection between the scale of the power plants and their cost-effectiveness led to economies of scale in production and transport, and consequently also the scale of government intervention needed to expand. Although at that time a system of obligatory national concessions was considered, it were the provincial governments that took the next step in the administrative organisation of electricity supply. Especially in rural areas provinces took the initiative to establish provincial electricity production companies. This step was motivated by pointing at the economies of scale that could be realised by provincial companies and to prevent rural areas from not being supplied with electricity because of high costs. Groningen and Brabant were the first provinces in which provincial electricity companies were established, South-Holland the last one because electricity companies were mainly organised at the municipal level due to its high degree of urbanisation. Electricity was available in every Dutch province in 1939, but not every Dutch citizen was yet connected to the electricity grid. Moreover a national electricity system had not yet emerged because the provincial electricity systems were not connected to each other.

The Second World War underlined the importance and the necessity of a national connected electricity system, and the realisation and perfection of such a system was an important post-war challenge. The first step was made in 1949 with the establishment of the Co-operative of Electricity Production Companies[6] (SEP), a body that was set up to give shape to the voluntary collaboration between the electricity production companies. SEP's main task was the construction of a national coupling network, something that was realised in 1954. As of that year the Netherlands was electrificated.

At the technical level also important steps were made (see also next section) and with the national connection of Dutch power plants this enabled significant increases in reliability of the system. The institutional organisation as well as the efficiency of the electricity supply was however considered far from optimal. The organisation of Dutch electricity supply consisted

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6 In Dutch: N.V. Samenwerkende Elektriciteits-Produktiebedrijven.

of a collection of relatively small, local operating, companies; production and distribution companies that were partly vertically integrated; some companies that solely distributed electricity; and a number of companies that combined electricity distribution with gas and/or water distribution. At the basis of this colourful collection of companies was a complex municipal and provincial ownership structure. Despite a process of reduction of the number of distribution companies especially the national government considered the efficiency of the national electricity supply far from optimal. From 1958 therefore efficiency was the key issue in the debate between government and the electricity sector.

In those days the central government aimed to strengthen national control of Dutch electricity supply for a number of reasons.[7] Objectives in this process were primarily oriented at efficiency of the segmented and differentiated electricity supply industry. Concentration of supply and introduction of a certain extent of competition in electricity production[8] were the main issues for the national government in a process that would take more than thirty years. The electricity supply industry offered resistance to increasing interference of national government and the associated corrosion of industrial autonomy and answered demands from national government with a stepwise increase of collaboration in SEP circles. The efficiency debate between the national government and the electricity industry stretched a period of thirty years, in which research was conducted, various committees released advice, strategic games were played, adjustments in the organisation of the electricity sector occurred, and in which eventually compromises were settled. Only in 1989 this political process was concluded with the introduction of the first national act for the electricity sector, the Electricity Act of 1989.

The pursuit of efficiency was translated in the law by the vertical disintegration of production and (high voltage) transmission on the one hand and electricity distribution at the other. The production of electricity was reserved for companies with a minimal production capacity of 2500 MW. As a consequence the 14 production companies merged to four regional production companies that produced electricity under the umbrella of SEP in a more co-ordinated

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[7] Apart from improving efficiency of electricity supply several other considerations played a role in strengthening national control: the rise of nuclear energy, the discovery of Dutch natural gas, the closure of the Dutch coal mines, and the desire to integrate various energy carriers in a national energy policy.

way.[9] They delivered electricity to distributing companies that distributed electricity to industrial consumers and households. However, distributors were not bound anymore to the electricity producer in their region, but could also purchase electricity elsewhere in the country.[10] This condition was expected to introduce a certain degree of competition between production companies, which in turn could increase efficiency in electricity production.

Next to this the Electricity Act of 1989 included another provision to promote competition in the electricity system, by facilitating the conditions under which de-central electricity production could take place. Industrial selfproducers of electricity were set to be able to deliver their surplus electricity to the national grid. This was also meant as an incentive to central producers to produce electricity more efficiently. The Electricity Act of 1989 strengthened the position of the SEP in the electricity system considerably. SEP became responsible for the long-term security of supply. Every two year SEP would publish an electricity plan in which the development of demand and supply of electricity for the coming ten years was outlined. Based on this plan, production companies planned new investments in production capacity. Distribution companies, which to a significant extent had direct and indirect ownership of production companies, felt they were increasingly submitted to the policy of SEP and tried to strengthen their position relative to SEP by mergers and clustering of interests. As a consequence, also in the distribution sector a process towards increasing scale and concentration took place, in which larger distribution companies with provincial ownership structures increasingly acquired the smaller municipal distribution companies (see table 2.1). The Electricity Act of 1989 accomplished therefore the decade-long strive for increasing scale and concentration in the Dutch electricity sector.

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[8] Governments were set to increase competition in electricity production by improving conditions for delivery to the national grid for decentral producers. Some industrial branches of Dutch industry already produced for own use since around 1920. The emergence of cogeneration technology led to primary production of heat (steam) for the own industrial processes and electricity was produced as a 'side product'. The delivery of this decentrally produced electricity has been a continuous source of argument between the electricity supply industry and the decentral industrial producers (see a.o. Blok (1993) and Arentsen et.al. (2000).

[9] This co-ordination consists of a system of technical and economic dispatch. In essence the system provides central co-ordination and balancing of production costs to spur production companies to produce electricity as efficient as possible.

[10] Due to the existing costpooling system in national electricity supply this opportunity of horizontal shopping did not lead to significant price advantages for distributors.

Table 2.1 Concentration in the distribution of electricity and gas

	electricity/gas	mono-gas	total number of companies
1950	225	118	343
1985	82	76	158
1994	29	12	41
1995	28	11	39
1996	23	11	34
1997	20	11	31
1998	16	10	26

The electricity act also initiated an unforeseen struggle between producers and distributors of electricity. Initially it looked like producers were on the upper hand, but the Electricity Act gave an opportunity to distributors which they exploited maximally. The act prohibited distributing companies to produce electricity, unless production capacity was less than 25 MW. However, this limitation did not apply for industrial selfproducers because the act was meant to enhance competition. De-central electricity production was also encouraged by national government in the framework of energy saving and environmental policy, because the technology of combined heat and power production, dominantly used by industrial selfproducers, led to significant energy saving. The distribution companies utilised the scope of electricity production for industries by establishing collaboration with industries in the construction and exploitation of cogeneration power plants.

These initiatives of distributors put pressure on the system of central electricity planning under co-ordination of SEP. The plans for capacity development did insufficiently take into account the rapid increase in de-central production capacity. As a consequence a considerable surplus capacity developed in the Dutch electricity market which threatened production of the four production companies. A moratorium on investments in de-central capacity was enacted to save the system of central production planning. In exchange the distributors negotiated new contract conditions for electricity delivery from the electricity producers.

Yet these initiatives were unable to turn the turbulent developments in the Dutch electricity system, more so because from 1990 on in various countries in Europe the first steps were made towards a liberalised electricity market. Also at the European level discussions were taking place regarding the harmonisation of the internal European electricity and gas markets, while in the Netherlands the installation of the first liberal-socialist coalition government in 1994 gave an impulse towards liberalisation. On the initiative of Minister Weijers from the Department of Economic Affairs the Dutch electricity sector was prepared for the slow but continuous increase of the market mechanism in Dutch electricity supply. The first liberal-socialist government chose, on the basis of the 96/92/EG EU directive for a far-reaching form of liberalisation of the Dutch electricity market, which was formalised in the Electricity Act of 1998. The Electricity Act of 1998 signifies the end of the monopolistic organisation of the Dutch electricity supply, a model that has dominated for more than a century.

Against this historical background the next chapter sketches the main socio-technical developments in the Dutch electricity system in the period from 1970-2000, the period on which this research is focussed.

3. Socio-technical development in the electricity system in the period 1970-2000

3.1 Introduction

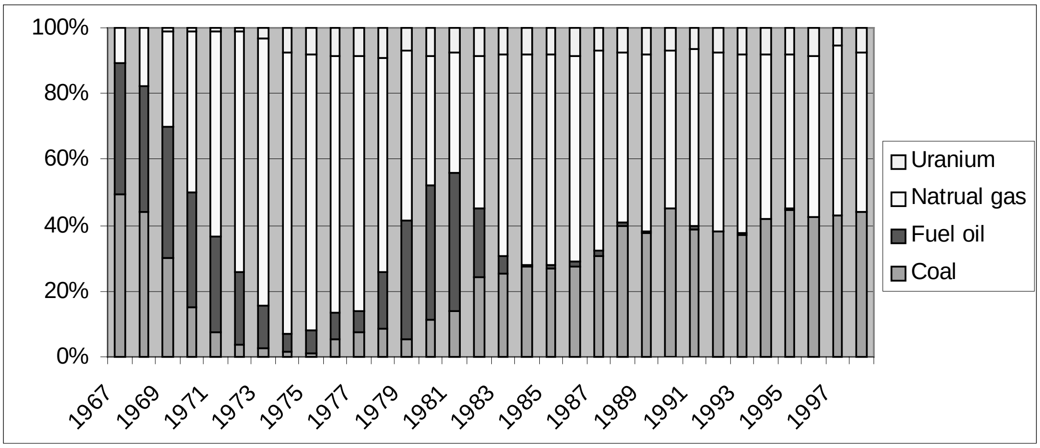
This chapter deals with the first research question of the research and describes the main developments in the Dutch electricity system for the period 1970-2000. Main components of the system are its fuel base, its electricity generation technologies, its system of transmission and distribution, and its consumption. In the first paragraphs we describe the development of these components and the way they fitted the design principles of the central station electricity model. We also analyse how these principles are related to the development of the energy knowledge infrastructure, institutional organisation, energy policy and R&D policies, and we assess how beliefs and expectations regarding the future of the energy system relate to this. This provides a first impression of core elements and mechanisms in the electricity regime, based on which we deepen our analysis in the next chapters. The second part of this chapter focusses on the development of alternatives to this central station electricity model and to the fossil base of the system. We focus on various technologies that provide alternatives to the dominant model through the use of alternative sources, alternative scales, alternative transmission routes, and alternative consumption concepts. Our aim is to get a first impression of elements in the electricity regime that are being pressured through combinations of developments in the sociotechnical landscape and niche developments. The next chapters will then build on these descriptions. We end this chapter with a concluding paragraph on sociotechnical development in the electricity system.

3.2 The fossil base of Dutch electricity generation

Geographical and geological conditions in the Netherlands have led to an electricity system 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 has not developed in the Netherlands. Moreover, geological conditions provided for coal and later 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. From the beginning of the sixties Dutch natural gas becomes available for the production of electricity and the share of coal drops in electricity generation. Natural gas has become the main fossil fuel in electricity generation as is shown in table 3.1, which gives an overview of the fuel base of the Dutch electricity system.

The table shows that fossil fuels are still dominant in electricity generation, with a very modest share for nuclear energy and renewable energy. Coal was the most important energy source until 1965 but natural gas gained dominance since then. In 1955 more than 90% of the input was coal, in 1965 this had decreased to 50% and in 1975 to less than 1%. The input of natural gas, less than 1% in 1965, rose to almost 90% in 1975. Through the years oil filled the gap next to coal and natural gas. The only significant exception to fossil input for electricity generation is the use of uranium. 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. Shortly after the oil crisis coal regained importance as an energy source and the role of oil as a source for electricity generation ended. Natural gas held its dominant position.

Figure 3.1 Input shares of primary sources for electricity generation, central producers, 1967 – 1998



Sources: SEP, VEEN/EnergieNed, 1988 – 1999; VDEN, 1980.

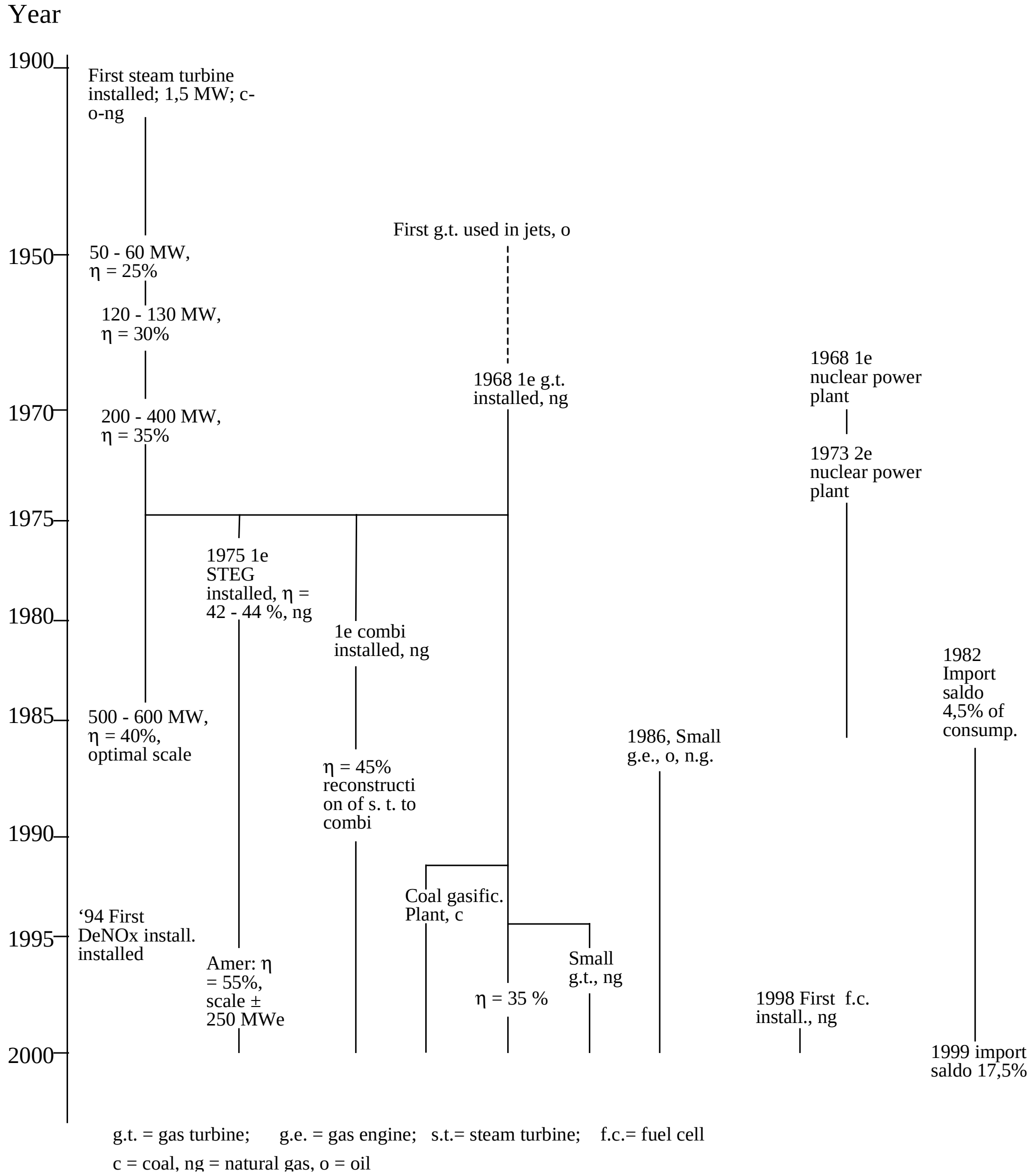
In short, Dutch electricity generation is foremost based on thermal power plants, and this has important repercussions for the development of generation and conversion technology in the Netherlands.

3.3 The technological base of the central station electricity model

Figure 3.2 on the next page depicts the major technological developments in generation technology and conversion technology in the Netherlands based on conventional fuel resources. The figure provides an overview of main developments in the period 1970-2000, specified to three types of electricity generation/conversion technologies. These three types are presented in separate columns. The first column presents the developments in the steam turbine trajectory, the second column for gas turbine technology, and the penultimate column represent developments in nuclear technology. Next to this two columns represent developments in fuel cells and small gas engines. The final column indicates the fact that the Netherlands imports electricity since 1982, among others from Germany, Belgium and France.

Thus, for each specific technological path (steam turbines, gas turbines, nuclear energy) a column is used. When a new technology for electricity generation emerges, the primary energy source it uses is listed. We briefly sketch the major developments in the next paragraphs.

Figure 3.2 Technological development in electricity generation with non-renewable sources



3.3.1 Steam turbine as dominant technology

The steam turbine was introduced at the beginning of the 20th century as a replacement of the steam engine. Between 1905 and 1910 the first steam turbines were installed with capacities around 1500 kW (Verbong, 2000). The company Stork supplied steam turbines in license since 1906. In 1913 the share of steam turbines in power production increased to 40%. Since then most of electricity production takes place with steam turbines. The basic principle is the conversion of fuel to heat in a steam boiler or reactor. Water runs in the boiler and forms steam of high pressure and temperature through heating. Expansion of steam leads to rotation of the axis of the steam turbine, the axis drives the generator through which electrical energy is produced (VDEN 1980, 92-93). Steam turbines can be heated with various fossil fuels such as gas, oil and coal. Until 1975 electricity generation technology mainly consisted of steam turbine technology.[11] 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 3.1 illustrates this increase in scale of generation units throughout the years.

Table 3.1 Scale and efficiency of steam turbines

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

Sources: VDEN 1980, SEP 1994, and interviews.

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 include the use of stronger materials and alloys, and the improvement of the turbines. A thermal efficiency for steam turbines of around 45% is considered to be the maximum for the conventional steam turbine[12] 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 is considered the optimum for the conventional steam turbine (Kleinbloesem, 2000).

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[11] In this section we treat power plants as entities. In fact they have been constructed of a number of elements, large and small. It would take too much detail to give attention to even some elements of power plants. In our characterisation therefore we focus on the conversion method in which primary energy is transformed into electricity.

[12] 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.

3.3.2 The emergence of the gas turbine

Since its introduction in electricity generation in the Netherlands in 1968 the gas turbine has quickly become a dominant technology for electricity generation. Although gas turbines were less efficient at that time in comparison to steam turbines with an efficiency of around 30%, they were useful because of their ability to operate fully within minutes from total standstill. This was very useful in periods of peak demand (Islas, 1997). Steam turbines in the beginning of the seventies were still more efficient for large-scale power generation (Verbong 2000). But operation of the conventional steam turbine at less than full power leads to more inefficient fuel use, something which is much less the case for gas turbines. It turned out that gas turbines filled in a specific niche by producing in periods of peak demand and by serving as additional back up capacity. Through the installation of small gas turbines, up to 50 MW, the electricity sector could improve the load factor of the large-scale steam turbines. This also safeguarded the reliability of the system, and reduced costs because it prevented the construction of large-scale power plants in order to deal with peak loads and to serve as back up capacity.[13] Other positive characteristics of the gas turbine were its compactness, its relatively low manufacturing costs and its short manufacturing time (Islas, 1997). The abundant natural gas reserves in the Netherlands also facilitated the diffusion of gas turbines (van Leeuwen, 1992). For the dominant performance characteristics of efficiency and continuous base load production the steam turbine was still superior. This however changed quickly. Gas turbine technology evolved quickly due to efforts by turbine producers such as General Electric and Westinghouse. Other companies such as Brown Boveri and Siemens built also on their expertise in the construction of steam turbines and on alliances with jet engine firms. These efforts were partly driven by the potential market for electricity generation and mainly by its primary market: the (military) aircraft industry (Islas, 1997).

3.3.3 Hybridisation of steam and gas turbines: combined cycles

A more radical breakthrough was made when a number of companies saw opportunities for application of gas turbine technology not only in the low load factor area of electricity generation but also for base load production. Swiss, British and American companies developed R&D programs in collaboration with electrical companies and with partial funding from public institutions (Islas 1997: 57). Dutch industry did not play a significant role in these

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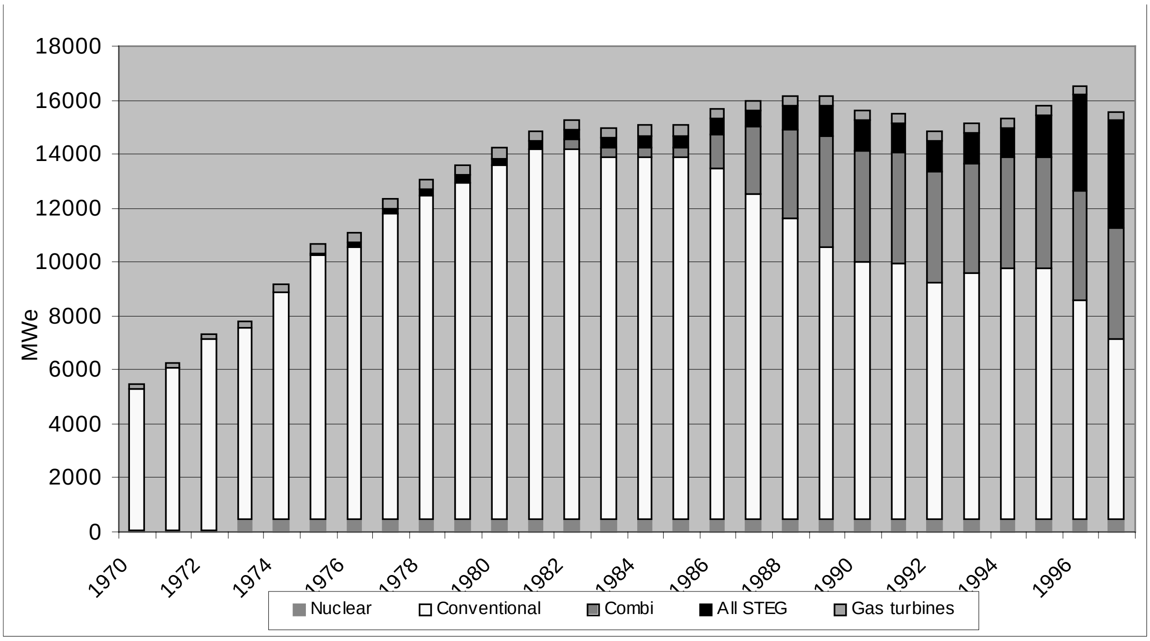
[13] Until then power plants were used for the base load (continuous electricity generation) during their technical life-time, in a second period served to deal with medium load, and finally were used to deal with peak demand and served as back up capacity (TK 1980, nrs. 11-12, p. 342).

developments and Dutch R&D funding was at that moment (sixties, early seventies) solely focused on the potential of nuclear energy. It turned out that combining gas turbines with steam turbines gave better results than the individual steam turbines. Combined cycles also slowly gained market share in the Netherlands and the last conventional steam turbines in the Netherlands were installed in the middle of the eighties (Kleinbloesem, 2000). Figure 3.3 shows how various types of gas turbine technology have penetrated central electricity production in the Netherlands.

Figure 3.3 Technology types used by central producers, 1970 - 1997



Sources: SEP, 1983, 1986, 1996; SEP, VEEN/EnergieNed, 1989 - 1998; ECN, 1998a; personal communications.[14]

Adding the gas turbine technology to the original single steam turbine cycle created this combined cycle generation unit and led to efficiencies of around 43 % (VDEN, 1980). In the early stages of hybridisation the gas turbine acted as an auxiliary device used to improve the performance of the steam turbine (the so-called combi). In this combi configuration the steam turbine can still use various fossil fuels as a heating source. In a second configuration, the steam and gas (STEG) configuration, the exhaust gasses of the gas turbine are used for production of steam that is led through a steam turbine. In this latter configuration the use of fuel for the generation of electricity could be reduced by 10 % as compared to conventional generation. In the period 1986 to 1989 therefore ten gas turbines were set up in connection with

[14] 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.

steam turbines, this was 25%, or 3650 MWe, of installed capacity at that moment (SEP, 1988: 57). Technological improvement of the combined cycle has led to installations with efficiency around 55% (Islas, 1999), such as the electricity generation plant of EPON in Eemshaven that came into operation in 1996 (Groeneveld 1998). For this installation the gas turbine cycle delivers around two thirds of the total of 335 MWe, the exhaust gases deliver the remaining one third through the additional steam cycle.

3.3.4 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 also 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 it did very well fit thinking in terms 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[15]). 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[16] differed from the principles under research by RCN. At that time there were therefore two research programs focussing on dif-

[15] Later this institute was renamed in Netherlands Energy Research Foundation (ECN).

ferent 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 electriciy industry started to gain the necessary knowledge by means of the joint research institute of generators, the KEMA and researched the developments in other countries. (Especially the US had an enormous head start over all other countries.) This can be seen as the start of the learning processes, because the actors had not gained any routines yet. 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 government budget for R&D in that period (Lagaaij & Verbong, 1999). Much of the government efforts were directed towards the build-up of a national nuclear industry.

Because of the cost, generators decided to buy a smaller plant than planned, which they should be able to use for research also. This made it possible to get new funding from Euratom. The SEP did not see much in the perspective of the involvement of Dutch industry[17] in the construction of (parts of) the reactor (Lagaaij & 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, 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 by a foreign company, and built in Borssele in 1973. This plant was based on the pressurised water reactor technology.

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[16] The KEMA was involved in the development of a Suspension Reactor (SR) from 1951on.

[17] Various industrial actors formed a consortium called Neratoom in 1959 to jointly develop 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.[18] 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 proliferation of nuclear arms began to emerge. This social resistance in the Netherlands became organised and the Dutch government was forced in 1978 to organise a national debate about nuclear energy that was ended in 1984 with a final report. In the national energy debate on future energy options, nuclear was among the most unfavourable options. The debate turned out to be more of a legitimisaton of an already set pro-nuclear course with backing of the natural science community, government and the electricity industry. Despite societal resistance, but in line with the resource diversification orientation in national energy policies, the Dutch government approved 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 terminating the only Dutch nuclear plant still in operation, in 2004.

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[18] Although provinces or municipalities owned the generators, they acted like private companies.

3.3.5 The introduction of technologies to reduce emission of power plants

The dominance of fossil fuels in the Dutch electricity system implied emissions of considerable amounts of hazardous substances, especially SO2, NOx and CO2. From the eighties on pressures increased to reduce these emissions, with acidification dominating the agenda. In the nineties emissions of CO2 become the dominant concern. Much of the technological efforts of the electricity sector in the eighties was put into reducing emissions, especially from SO2 and NOx. Desulphurization equipment was installed at coal-fired power plants at the end of the eighties. Pilot projects with deNOx equipment were initiated in the same period and both deNOx installations and low NOx burners were increasingly installed in the course of the nineties (van Leeuwen, 1992, den Hartog, 1992).

Figure 3.4 (on the next page) indicates a decrease in emissions of NO_x and SO_2 from the middle of the eighties on. Fluctuations in SO_2 emissions are until the middle of the eighties related to the share of coal in the fuel mix of the central power plants. From that period on SO_2 abatement techniques[19] were installed at coal-fired plants, first in two demonstration plants and later in all coal-fired plants (Wiersma, 1989; Lulofs, 1999).

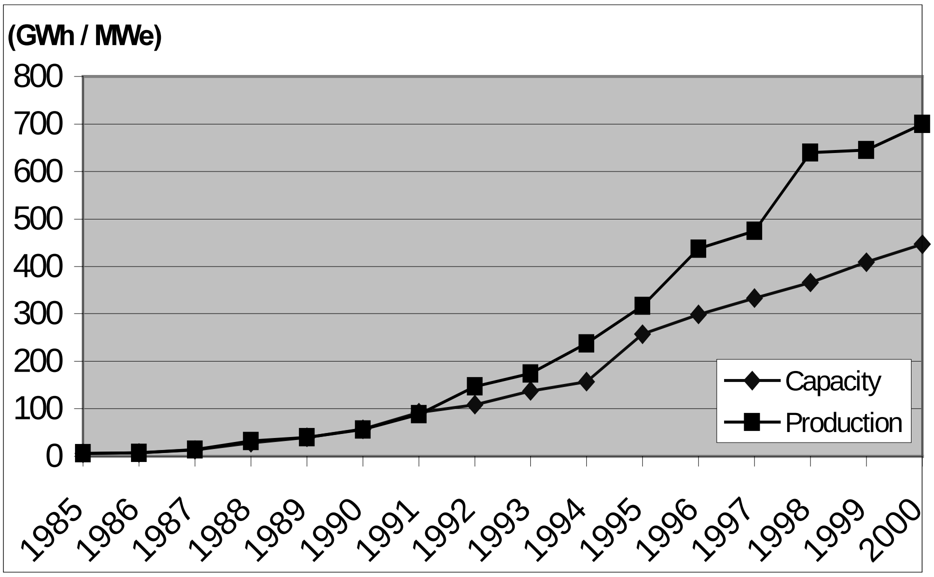
Reduction of NO_x emissions was realised by various measures. Several conventional gas/oil fired units were pre-connected with gas turbines, thus improving overall efficiency and reducing emissions of NO_x. Also deNO_x equipment was installed throughout the nineties with first demonstration projects 1990. Experience was already available in around 140 DeNO_x installations in Germany (den Hartog, 1992). The development of so-called low NO_x burners has steadily reduced NO_x emissions of gas turbines. All major gas turbine producers have made efforts in developing low NO_x burners (Crone, 1995).

Low efficiency of steam turbines and the relative poor environmental performance of coal-fired plants also led to the implementation of a coal gasification plant for electricity production. The gasification concept was developed by Shell as a means to reduce its long term dependence on oil (Zon, 2000). The gas turbine used in the demonstration plant was developed by Siemens (Dijkgraaf, 1996, pp. 26). The construction of a 253 MWe coal gasification demonstration plant in Buggenum started in 1992. This plant, an integrated coal gasification

[19] Dutch power plants exclusively use the gypsum/acid process for SO_2 abatement. The gypsum can be used as a side-product in the construction sector. The technique was available and was custom-made through several demonstration projects (Wiersma, 1989; Lulofs, 1999).

combined cycle (IGCCC)[20], was the largest plant of this kind ever built in the world. The plant reached a net efficiency of 43,5%. It is expected that an efficiency of 51% is possible through larger scale and modifications in the gas turbine (Ybema et al, 1995; Zon, 2000). In 1994 the plant started as a demonstration unit to prove large-scale gasification of coal is a technological and economical alternative for natural gas and conventional coal power plants with environmental characteristics similar to gas firing. In 1997 the plant came in full operation.

Figure 3.4 Emissions and production of central power plants 1960-1998 (1980 = 100)

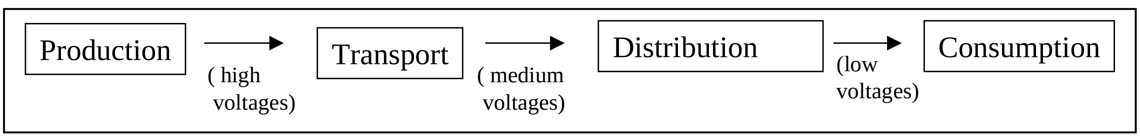


Sources: RIVM, *Milieubalans 1998 en 2000*, 1999, 2001; CBS, 2000

3.4 Transmission and distribution in the central station electricity model

In the central station electricity model electricity is produced in several generation units and consequently transported and distributed to customers. Virtually every building in the Netherlands is connected to the grid through cable networks that can carry electricity of different voltages[21]. Figure 3.5 illustrates this.

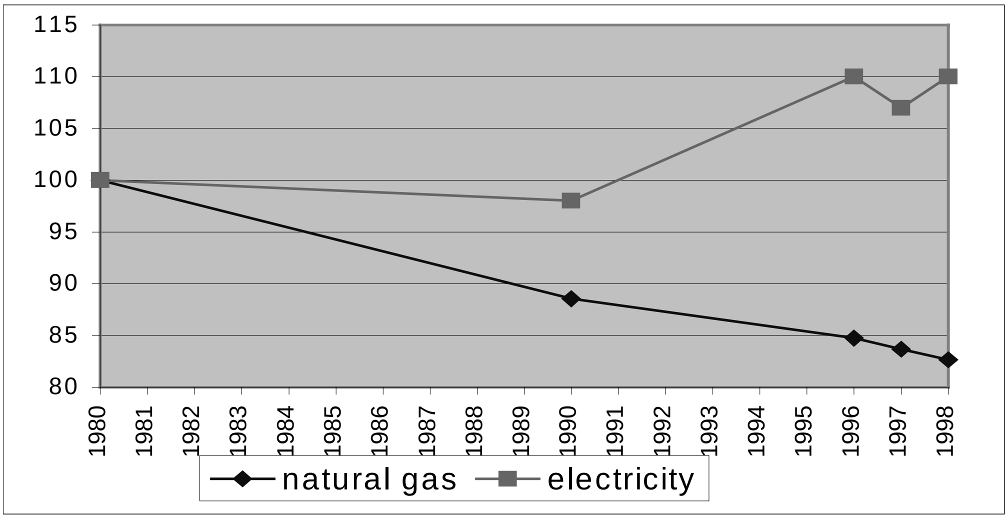
Figure 3.5 Transmission in the electricity system



[20] In Dutch a KV / STEG.

Over the years the development of the grid has demanded considerable investments from electricity generating companies. In the 1976 to 1978 of average annual investments of around 2 billion guilders, 57 to 59% was related to the development of the grid (SEP 1979: 45). This percentage significantly dropped in the course of the eighties, with in the period 1986-1989 between 25 and 30 % of annual 2 to 2.5 billion guilders investments in electricity generation were related to the development of the grid (SEP, 1990: 41). The grid has continuously expanded in both length and carrying capacity over the years. Figure 3.6 illustrates the expansion of both the low voltage and high voltage grid in the last 30 years.

Figure 3.6 Length of distribution nets[1], 1967 - 1998



Sources: SEP, VEEN/EnergieNed, *Electricity in the Netherlands 1997,* 1998; CBS, 1999.

The development of a national power grid was considered necessary because pooling of the various electricity production units leads to higher reliability and makes it possible to decrease the backup capacity for electricity generation (VDEN, 1977, 1980). Mutual pooling of all public Dutch electricity generating plants was realised in 1953 (VDEN, 1977: 70). Because of the larger scale of the generation units pooling through the high voltage grid now takes place with a 380 kV net[22]. In the nineties further expansion of the high voltage net took place through connections at 380 kV with Germany, and a further international high voltage con-

[21] A low voltage net (220/380 volt) is used for final delivery to customers. The medium voltage net (3 to 50 kV) is used for transport and distribution and the high voltage net (110 to 380 kV) is used for transport by pooling the various generation units and for import and export of electricity.

[22] Further optimisation of the system took place by the introduction of a national economic optimisation system in 1982 that calculated which units should be applied to generate electricity in the most cost-effective way. As a consequence transport of electricity on the high voltage grid increased by 28% in 1982 compared to 1981 (SEP 1982). In the eighties SEP decided to further expand the high voltage 380 kV net and to form a ring of 380 kV in order to prevent capacity problems in the case of fall out of installations.

nection was planned with Norway (SEP 1994, 1996). From 1998 on, a specific operating organisation for the high voltage network (380 and 220 kV) was set up, Tennet, to replace the previous collective responsibility of the SEP. The low voltage distribution networks are under ownership of the electricity distribution companies. A high degree of ‘perfection’ of the Dutch electricity grid has to be maintained to serve these goals and to prevent fall-out of electricity. Dutch fall-out of electricity is low in comparison to other countries (Steetskamp & van Wijk, 1994). The duration of malfunction is among the lowest in the world with a recently report annual average fall-out period of 22 minutes (EnergieNed, 2000). Apart from good maintenance and steady strengthening of the grid,[23] also a relative high level of stand-by power contributes to this.

In conclusion the development of the electricity grid has traditionally served the following goals:

- Distribution of electricity to customers;
- Safeguarding reliability by connecting various production units;
- Fine tuning supply and demand by switching (peak demand) units on and off;
- Optimising efficiency by using the cheapest production units for the base load.

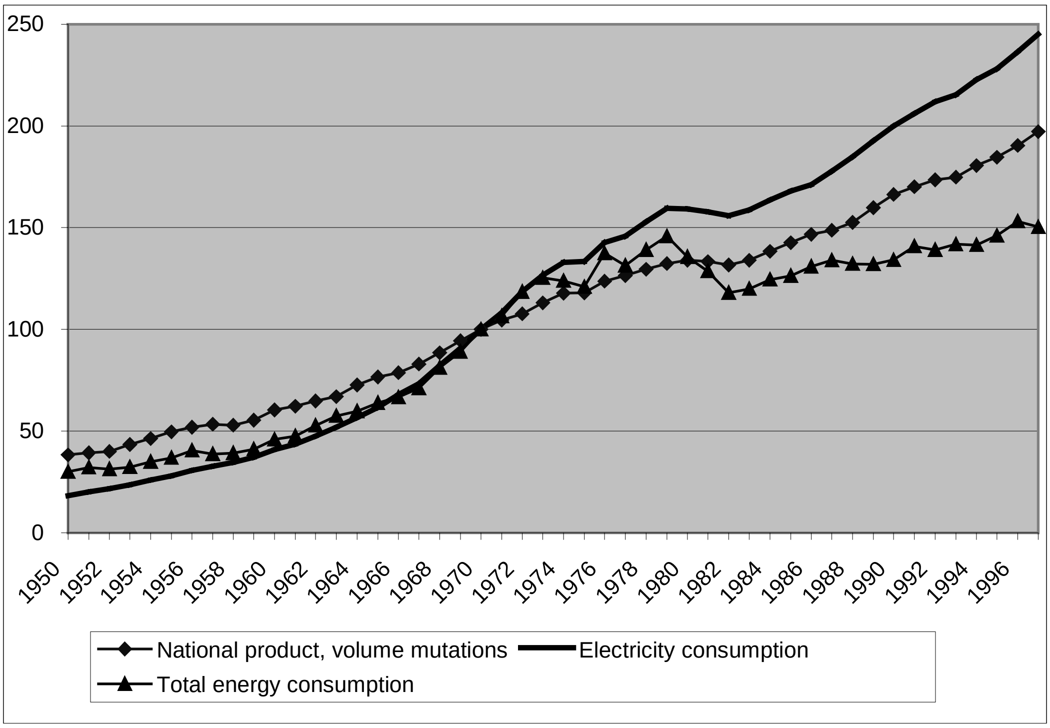
The dominant function of the electricity network throughout the years has been to transport and distribute centrally generated electricity to customers. The network has been primarily constructed to transport electricity from producers at high and medium voltages to transformers that distribute electricity at low voltages to consumers. Several developments are increasingly challenging the perception of the grid as a one way channel of distributing electricity. The fast growth of combined heat and power generation at the end of the eighties and beginning of the nineties increasingly led to electricity production by non traditional producers and affected the controllability of the system. Emerging decentral systems producing electricity based on renewable sources or micro CHP imply a even more complex two-way flow of electricity. Research and knowledge on this is still in its infant stage (Rooijers et al, 1996; Meij, 1999; Zewald 2000).

[23] The fact that the grid is mainly underground also reduces fall out (EnergieNed, 2000).

3.5 The development of electricity consumption

The development in electricity demand has kept track with the economic development of the industrial society. Until approximately 1970 consumption doubled every ten years. The oil crises in the 1970s and decreasing economic growth rates slowed down the increase in electricity consumption, but in general the share of electricity in the overall national energy demand has increased significantly over the last decades. Figure 3.7 below gives and overview. The figure shows that energy is increasingly consumed in the form of electricity.

Figure 3.7 Indices for electricity consumption, energy consumption and gross national product, index 1970 = 100.



Source: Own calculations on basis of CBS data.

The significance of electricity for the Dutch society also appears from the elasticities[24] for energy and electricity consumption (see table 3.2 below). In the period 1970-1980 a one percent increase in economic growth is associated with a 1,7% increase in electricity use and a 1,06 increase in energy use. Energy use has slowed down relative to economic growth in the period 1986-1995 with a one percent increase in economic growth is associated with a 0,5% increase

[24] The elasticities, calculated as (growth energy use / gross national product), represent the proportion with which the energy use will rise as the gross national product rises with a certain amount. This relation is strictly statistic of nature.

in energy use. In the same period a one percent increase in economic growth is associated with a 1,2% increase in electricity use, a clear indicator for the ongoing electrification.

Table 3.2 Elasticities between economic growth and energy use; and economic growth and electricity use

	1970-1980	1986 – 1997
Electricity use	1.74	1.20
Total energy use	1.06	0.50

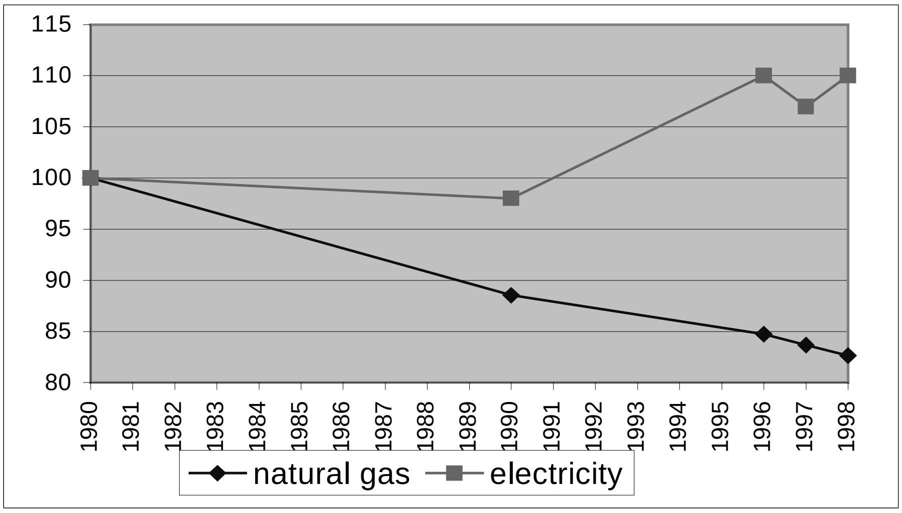
Source: Own calculations on basis of CBS data.

The distinction of electricity consumption into several consumer groups is relevant in order to characterise producer-consumer relationships. The amount of electricity used is the main criterion in this distinction, and has also been an important criterion in the contracts that have been established between producers and consumers. Electricity consumers can be divided into large users, such as giant industrial users; medium users, such as SMEs; and small users, such as households. In the following section we focus on electricity consumption in households to illustrate the trend towards electrification.

Development of the electricity use in households

The process of electrification is visible at the level of households. Energy use in households in the form of electricity is steadily replacing gas as an energy source, as is shown in figure 3.8.

Figure 3.8 Development of electricity and gas use per household (Indices, 1980 = 100)



Source: CBS, 2001

Electricity is increasingly part of products that have penetrated almost every household and office. The functioning of computers, television, radio, audio, household appliances depend on electricity and its use and availability as a power source is accepted as a basic human need. In the next table an example is given of the penetration of household equipment that uses electricity. The table also shows that the use in kWh of most of the appliances has decreased in the last decades. This is caused by an increase in energy efficiency. However, increasing penetration leads to ongoing increases of electricity consumption in households.

Table 3.3 Penetration of household equipment and electricity use

	1973		1993		1997	
	Penetration (%)	Use (kWh)	Penetration %	Use (kWh)	Penetration (%)	Use (kWh)
Refrigerator	88	450	105	350	112	342
Freezer	17	800	49	380	55	380
Television	96	175	154	149	171	99
Dishwasher	4	900	15	360	29	305
Washer	85	450	97	236	98	231
Dryer	5	700	42	530	54	542
Boiler	16	1750	18	1385	19	1290
Heating boiler	30	500	61	290	77	283

Source: ECN, , *EVN 1994, EVN 1997, EVN 1998*, 1995, 1998, 1999

Electrification also takes place through the emergence of new products based on electricity as an energy source. For example, the information revolution has also led to increasing use of electricity based equipment. In earlier decades electrification took place through adaptation of existing equipment. The last decades witnessed the emergence of new apparatus powered by electricity. This development is still present. In table 3.4 it is shown how new electrical equipment is penetrating households in the Netherlands.

Table 3.4 Possession in households of electrical apparatus (%)

Apparatus Type	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Sewing machine	66	65	65	64	62	64	64	64	63	62
Micro wave oven	2	5	9	16	22	29	38	43	51	56
Video recorder	30	36	41	45	50	56	60	65	68	70
Video camera	.	3	3	5	7	9	12	14	16	16
Slide projector	30	28	27	35	24	25	25	25	25	24
Home-PC	11	14	18	21	25	29	31	34	39	43
Tape recorder	74	75	78	80	81	84	85	87	86	86
Record player	81	81	82	82	80	80	77	77	73	71
CD player	6	15	25	38	48	59	66	71	75	78
Solarium	.	.	4	3	4	6	7	9	12	12
D.A.T. recorder	.	.	.	1	1	1	1	1	1	1
TV-game computer	.	.	.	.	.	.	9	12	13	13
D.C.C. player	.	.	.	.	.	.	0	1	1	1
Minidisk player	.	.	.	.	.	.	.	3	5	5

Source: CBS, 2000.

In recent years the development of information technologies has had a significant impact on the electricity system. The growth of electricity consumption is strongly related to the penetration of information technology. It is for example estimated that in the USA around 20% of electricity use now takes place through computers and the internet (Zon, 2000). Fast growth of internet and computer related companies in a new business area in Amsterdam is linked to a concentration of growth of electricity use in the area. This has led to problems with electricity distribution due to overburdening of the local grid.

3.6 The institutional base of the central station electricity model

The Dutch electricity system, still predominantly publicly owned, developed out of small scale municipal electricity companies, established in the first decades of last century (see also chapter 2). Between 1950 and 1989, electricity generation and distribution was organised in small scale monopolies, with clearly defined positions and legally authorised tasks reflecting the public utility character of electricity supply and the company's public service obligations. Until 1989 the system was publicly owned and public service oriented in operation and performance.

At the beginning of the 1960s the then Dutch government started debating scale and scope of the national electricity system, to improve its economic performance (efficiency) but not releasing its overall public service orientation on security and reliability of supply and low tariffs. Before 1985 generation, transport and distribution was integrated in 14 larger generation/distribution companies in leading market positions. Ten of them with provincial ownership structures and regionally based, and four with municipal ownership structure, operating in the urban areas in the western part of the country. The 1985 debate reinforced the need to concentrate. Distribution and generation disintegrated and, mergers reduced the number of generation companies to four.[25] SEP reinforced its leading and managing position in generation, and headed the technical and economic dispatch of the power plants owned by the four generation companies. SEP also headed the high voltage transport and import and export of electricity and the forecast of electricity demand and supply, legally obliged by the electricity act of 1989. Distribution companies continued merging, hoping for efficiency improvements by increasing the scale of business. The mergers swallowed relatively small

[25] The initiative to disintegrate generation and distribution was actually taken by the Dutch government of that time. For a more detailed description of the debate see, Arentsen, Künneke and Moll, 1997.

scale municipally owned distribution companies and were taken over by the provincial owned larger companies. The electricity act 1989 reflected and authorised this newly established structure in the electricity system as it developed between 1985 and 1989.

The electricity act 1989 authorised the new electricity landscape as it was redesigned by industry itself. From 1989 on, division of generation and distribution was legally obliged[26], but the newly established legal order incorporated two rather significant tensions. Firstly, the electricity act 1989 separated generation and distribution, but did not change the ownership structure, bringing distribution companies in an ambiguous position as shareholder and as customer of generators. Secondly, the act opened up ways for distribution companies to produce electricity outside the central generation capacity co-ordinated by SEP. And indeed happened what could be expected: distribution companies started generating electricity, in fact rather strategically. They invested in CHP-technology, in many cases in joint venture with private industry, putting pressure on the centrally co-ordinated electricity generation. At the time distributors started their investments, CHP-technology became strongly supported by government for environmental reasons and with the help and support of private industry, distributors eroded the monopolistic price setting of the generation companies by creating overcapacity in the system. SEP and the generators were forced to negotiate an agreement with distributors to manage surplus capacities. In this way distributors managed to reshuffle positions vis à vis generation companies favourable to their own position, but, paradoxically, the distribution companies, successfully competing generation as customers, at the same time competed themselves as shareholders.

The complex ownership-customer relationship and clearly different interest positions of generation and distribution could only be released by restructuring the national electricity market again rather shortly after the 1989 revision. Yet the ongoing European debate on liberalisation mitigated the institutional tensions in the Dutch electricity system during a couple of years. In between Dutch public authorities took advanced positions in the European debate on liberalisation, guided by a domestic change in political climate. The social liberal coalition took over power in 1994 from the conservative coalition, which had been in power for two decades and was dominated by Christian democrats. The new coalition, strongly advocating liberalisation and deregulation, launched a White Paper on energy, which designed a new order for the na-

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[26] One of the major reasons for this structure was to improve the conditions for the development of CHP and sustainable electricity.

tional electricity system by the end of 1995[27]. In fact, the White Paper reflected liberalisation proposals developed and discussed by the European Union to harmonise the internal electricity and gas market. Dutch Parliament accepted and approved the liberalisation ideas proposed by the social liberal coalition, marking the point of no return that accelerated the process of restructuring the national electricity supply industry. At the same time the EU accepted the final draft of the EU-liberalisation directive and the Dutch government took the next step in designing the new structure for the national electricity market that finally resulted in a proposal of a new electricity law by the end of 1997, and the inauguration of this law in 1998.

The new electricity act reflects a rather liberal interpretation of the EU-directive 96/92/EG. Table 3.5 illustrates the main changes in the value chain of electricity as proposed by the new electricity act.

Table 3.5 The old and new institutional organisation of the electricity system in the Netherlands

Value chain	**Before 1998**	**After 1998**
Generation	Long term strategic and operational planning Central economic and technical dispatch	Free and unconditional except standard legal obligations
Transport/ Services	De facto SEP monopoly Technical dispatch by SEP, from 1989 on also economic dispatch Internal rules electricity industry	Monopoly of the grid company Free access based on a system of regulated TPA Independent system operator
Distribution	Geographic monopoly distribution company	System of licenses to supply captive customers Tariff regulation and efficiency measures
Wholesale	De facto SEP monopoly on import and export[28]	No restriction, but imports on the base of reciprocity
Retailing	Not operational, integrated with distribution	Free with the exception of grid companies Stepwise free choice electricity supplier
Products and services	No (commercial) services in combination with electricity supply allowed	No restrictions on products and services

[27] Derde Energienota , Dutch Parliament 1995-1996, 24 525, nrs. 1-2.
[28] The Electricity Act 1989 did allow for direct import of electricity by of giant consumers, but the tariff structure on transport made the imports de facto inefficient, leaving SEP in a de facto monopoly position.

The act obliges an administrative and financial unbundling of generation, trade and supply on the one hand and transmission and distribution on the other. Access to the grid is arranged as regulated TPA and the market will be liberalised stepwise, beginning in 1999 (650 giant consumers > 2MW, representing 34% of the market), next in 2002 (some 56.000 small industrial consumers up to 3*80 Amp, representing 27% of the market) and finally in 2007 (some 6.7 million households, representing 39% of the market). The act also launched the regulator for market control and tariffs and introduced privatisation as a theme, but did not really opened the discussion yet[29]. In November 1999 the minister for Economic Affairs published an Energy Report in which the acceleration of the eligibility of customers was announced. Contrary to the original ideas, the Energy Report suggested the eligibility of the middle group of smaller industrial consumers before 2002 and eligibility of all Dutch consumers not in 2007 but in 2003 at the latest.[30]

The structural changes in the Dutch electricity system during the last fifteen years basically reflected the need to improve efficiencies. Dutch prices were among the lowest in Europe in the early nineties, but still too high as was proven by the distributors with their CHP-investments. They offered electricity two cents under SEP-tariffs and, in no time, they managed to conquer a market share of some 22%. Liberalisation didn’t change the transition process that started after 1985, but reinforced the need to improve efficiencies. As a result, Dutch distributors persisted in the merger process and Dutch producers, only four left, were challenged by the ‘efficiency regime’ of SEP, forcing them to generate as efficient as possible. At the operational level, generation and distribution continued co-operation as in the old days, but at the strategic level, they stipulated market power in the debate to merge the four generation companies as one giant national generator. The debate on the establishment of one giant Dutch producer is one of the two manifestations of the power game that has been played by the Dutch energy companies over the last fifteen years. The second manifestation is the increase in business scale and scope of distribution companies. From 1989 on generators and distributors disputed power dominance in the Dutch market, a dispute that definitely was resolved by the failure of the merger of the four generation companies into one giant national producer early 1998.

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29 The new electricity act maximises privatisation to one third of the shares of distribution companies and to half of the shares of generation companies.

30 Ministry of Eeconomic Affairs, 1999a, p. 26.

Since 1999, the year in which liberalisation was launched in the Dutch electricity markets, the organisation of the Dutch electricity industry changed drastically. Although the merger between the four power generators failed, concentration in energy distribution continued. At this moment three giant energy companies dominate the Dutch market and each of them has adopted in one way or another to the multi-utility concept of organisation, offering all kinds of energy products (electricity, gas, heat and cold) as well as other types of utilities, such as water, telecom and waste treatment.

The major impact of liberalisation has been the changeover from the monopoly model to the market-based model. Liberalisation in this way closed the historical cycle of institutional development of the electricity system. The system developed out of private initiatives of private firms starting to generate and distribute electricity at a local level. From there the state dominated model started to develop stepwise increasing the state control of the electricity industry. After almost a century of development the monopolistic institutional organisation and state control is changed towards a liberalised model, putting the state in a position of regulator and leaving the production and supply of electricity to market actors.

3.7 The knowledge base of the central station electricity model

3.7.1 Nuclear energy dominates the agenda: period until the first oil crisis

In the sixties and the seventies the dominant belief and perception of the electricity supply sector is that 'nuclear energy is the future of electricity generation and we can develop it ourselves'. The scarcity of, and dependency on, fossil sources, especially oil, also shape positive expectations regarding nuclear energy. Nuclear energy fits very well in the perspective of the sector of large-scale units of generation that concentrate production of electricity that is consequently distributed to customers along a well-developed grid. These are guiding principles dominating electricity generation since the early 1900s. It also fits investment decisions in terms of investing heavily in large units for the long term, with high reliability, based on a highly developed grid, and in the perspective of continued growth, irrespective of specific customer demands. The belief of government actors is that nuclear energy is destined to become responsible for a large share of electricity generation. A parallel objective is to develop a national nuclear industry. Until the end of the seventies therefore large parts of budgets for scientific policy, technology/industrial policy and energy policy are spent on nuclear R&D.

An important factor driving larger economies of scale were the high levels of economic growth in combination with a sharp increase of electricity use. In the beginning of the seventies it was expected that electricity use would double every ten years. This would mean a huge expansion of electricity generation capacity.

Table 3.6 illustrates the expectations in 1972 regarding electricity demand and supply in the coming decades.

Table 3.6 Prognosis in 1972 regarding electricity supply, in thousands of MWe

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

Source: TK 1972, White Paper regarding Nuclear Energy, TK Zitting 1971-1972, 11761, p.2.

The expectation of continued growth meant that the system needed to expand rapidly in order to safeguard reliability of electricity delivery. At that time it was expected that nuclear energy would be a secure and cost-effective source for electricity. Reliability has always been a prime criterion for the development of the electricity system. For example in the fifties, government voiced that “electricity is an indispensable technical condition for the good functioning of our society” (Handelingen der Staten-Generaal, 1951-1952).

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[31] and RCN[32] almost exclusively involved in nuclear research and set up after the Second World War to develop Dutch nuclear energy research. From 1952 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

[31] FOM, the National Research Organisation for Fundamental Research, was set up in 1946 to co-ordinate nuclear research (Lagaaij &Verbong 1999: 38).
[32] 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 & Verbong 1999: 39).

by a focus on nuclear research[33]. According to a pioneer in renewable energy in that period academic energy research was dominated by around 20 to 30 professors in nuclear related 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 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.[34]

3.7.2 After the oil crisis: developing an energy research agenda

The oil crisis had a major influence on directions of energy research. The set up of a national steering commission for energy research (LSEO), enacted in 1974 by the minister of scientific policy to direct long term priorities in energy research, reflected the change in energy policy. The installation of the LSEO also marks the start of first efforts towards development of electricity supply options other than nuclear and fossil based. The national research centre for nuclear energy RCN was renamed to ECN, Energy Research Centre of the Netherlands, in 1976 and broadened its research to other energy sources next to nuclear energy. Also various programs on renewable energy sources were started from 1976 onwards with ECN as coordinating organisation. To prevent entwining of interest a specific project management office is founded in 1977 at ECN, called BEOP. In the period 1976-1985 a national solar energy

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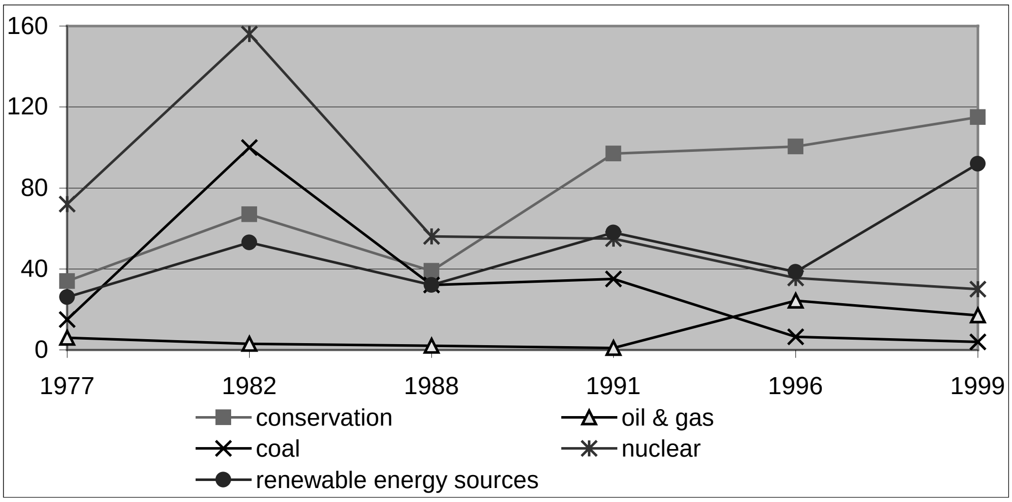
[33] The number of actors initially involved in decision making regarding nuclear energy and nuclear R&D is limited. An analysis of the network with regard to nuclear energy in the seventies showed that only a small number of engineers form the backbone of this network (Uitham et al in Lintsen (1985). 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).

[34] 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).

R&D program was carried out. In the first phase until 1982 research was focussed on thermal solar energy with a budget of around 10 mln guilders (REO, 1981). In the second phase (1982-1985) around 20% of the budget of 20 million guilders was focussed on non-thermal conversion (TK 1982-1983: 114). In 1976 a national program on wind energy was initiated for a period of five years and with a budget of 20 million guilders (under co-ordination of BEOP). Public spending on renewable energy in that period was however small compared to ongoing efforts on nuclear energy, and renewed efforts on coal.

Figure 3.9 shows that public spending on R&D in nuclear energy and coal remain dominant until the mid eighties.

Figure 3.9 Public spending on energy R&D, 1977-1999.

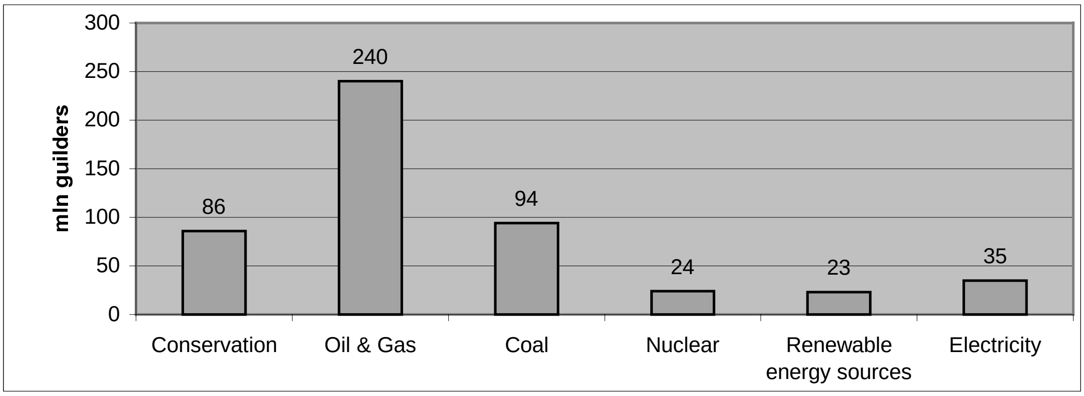


Sources: REO, 1981; VDEN, 1980; REO, 1983; TK, Rijksbegroting 1989; TK, Rijksbegroting 1991; Ministry of Economic Affairs, 1998, 2001.

The role of coal in Dutch energy supply had been largely diminished at the end of the sixties and beginning of the seventies. However, in the first White Paper on Energy of 1974 it was announced that coal use for electricity production would increase in order to reduce gas use (TK 1974: 113). In the second White Paper on Energy of 1979 an outline for a national research program for coal is presented. The coal research plan is set up to develop new coal technologies, especially gasification of coal, and techniques to reduce the negative environmental impacts of electricity generation through coal, such as treatment of SO_2 and NO_x emissions. The program was proposed to be financed by 750 million guilders in the period 1980-1985, with around 150 million for research and 600 million for demonstration (TK 1980: 86, 107). Actual spending on the program was somewhat lower as is also shown in figure 3.12. The R&D budget for coal decreased at the end of the eighties and beginning of the nineties when environmental concerns gained more prominence on the political agenda. Several reports with worrisome conclusions regarding the effects of acidification and ongoing depositing of acid substances played a role in this (Dinkelman 1995, Hajer 1995). In an extension to the Dutch environmental policy plan intensification of the reduction of CO_2-emissions is introduced, among others through reduction and discouragement of coal use (Ministry of VROM, 1990).

Apart from public spending on energy R&D also significant investments in energy R&D take place in the private sector. For 1981 it is estimated that private funded energy R&D is around 520 million guilders as to 365 million guilders public funded energy R&D (REO, 1983). Directions of private energy R&D are significantly different from public funded energy R&D. Figure 3.10 gives the breakdown of energy R&D for various research fields in 1981. Important actors in private energy R&D are the electricity supply industry with its R&D institute Kema, and the gas sector with the R&D institutes Gastec and Gasunie research.

Figure 3.10 Private energy R&D in 1981



Source: REO, 1983

For 1993 figures are estimated at 358 million guilders for private funded energy R&D and 326 million guilders for public funded energy R&D (Weijnen, 1994). Specific details on the breakdown to various R&D fields are not available, although it is clear that R&D for coal is around one third of the total due to investment in the Demkolec coal gasification plant with 110 million guilders annually in the period 1992-1994.

3.7.3 The eighties: the ‘National Energy Debate’[35] shapes the agenda

The 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. Resistance against the planned choice for extension of the number of nuclear energy power plants led the government to set up the BMD as a way to make decision making regarding future energy supply more legitimate. In the discussion various groups, organisations and individuals voiced their ideas and expectations regarding the future energy system.

The BMD made clear that opinions regarding the future energy supply differed widely[36]. 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[37]). 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;
- Application of nuclear energy reduces our dependency and improves stability of prices.

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[35] In Dutch: Brede Maatschappelijke Discussie. The BMD was initiated by Dutch Government to discuss the future of energy supply in the Netherlands. The hidden agenda was to increase acceptance for the further installation of a number of nuclear energy power plants.

[36] Stuurgroep Maatschappelijke Discussie Energiebeleid, Eindrapport BMD, 1983, pp. 3.

[37] 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.

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[38]. 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[39].

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:[40]

- 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.

3.7.4 The nineties: the climate problem starts to dominate the agenda

Environmental concerns have played a significant role in considerations regarding electricity supply. In the belief system of the electricity sector environmental demands foremost play a

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

restrictive role in electricity supply and are secondary to the fundamental technological configuration. Early environmental concerns regarding emissions of SO_2 and NO_x could be dealt with without changing the fundamentals of the technological configuration. Additional design and research activities were created to deal with these emissions leading to desulphatisation and deNO_x techniques and optimisation of process temperatures. Increasing the use of natural gas also decreased overall emissions of SO_2 and NO_x. From the eighties on, the disciplines of electrical and mechanical are supported by a third leg, environmental engineering with a focus on techniques to reduce environmental impacts of traditional power plants (Zewald, 2000).

Emissions of CO_2, however, pose a more fundamental problem to the fossil based electricity regime. Climate change has become a dominant topic on the political agenda and the electricity sector is pressured to reduce its CO_2 emissions. Apart from strategies that do not fundamentally change the technological configuration of electricity generation and distribution in the Netherlands (increasing efficiency, switching to natural gas, co-combustion with biomass, forest plantations in other countries, upscaling technology in Eastern Europe) the belief in the electricity production sector has been that climate change:

- is an international problem in which the Netherlands has already significantly reduced its burden, and has one of the most efficient electricity production systems in the world;
- should first be tackled in other countries where obsolete coal technologies are use, such as Eastern Europe and China;
- is not yet validated.

It is clear that the sense of urgency of the climate change problem differs among various groups. Interviews with various representatives of the electricity sector made clear this sense of urgency is among the lowest in the electricity sector. This view is also shared by various actors in research institutes and universities that have strong links with the fossil based regime. General arguments are that increase of the CO_2 degree in the atmosphere is an autonomous process (Kouffeld, 1998) and that the influence of human induced increases CO_2 emissions on climate change can be questioned (Böttcher, 1999, Zewald, 2000, Zon, 2000). In these circles the concern regarding the finiteness of fossil fuels, gas in particular, is much stronger than concern over climate change. This is associated with the expectation that the future of electricity generation is largely dependent on the availability and use of fossil fuels, coal in particular, and the use of nuclear energy. Illustrative is a recent publication of the former leader of the liberal party, now EU commisioner, Bolkestein[41]:

> 'The only energy sources that are available in the long term are coal and nuclear energy (….) The Netherlands focuses long term energy policy towards the extinct sources oil and gas and extinguishes sources which are available in the long term' (Bolkestein, 2000).

The expected importance of coal is based on its ample supply and the development of coal gasification technology: "Coal can serve as a long term source for electricity generation, with coal gasification an attractive technological path. On a world scale it can become one of the most important options for electricity generation" (Böttcher, 1999). Oil companies have invested in the development of the coal gasification technology for the same reasons, the synthesis gas formed can provide input for current processes in both the chemical and oil industry. An additional advantage is said to be that in the process of gasification it is relatively easy to separate CO_2 gas, for example in order to store it (Zon, 2000).

In the first National Environmental Policy Plan the issue of climate change takes a prominent place. Programming of energy R&D reflect the growing importance of this policy issue. Energy conservation is considered one of the most viable options to reduce CO_2-emissions and therefore in the nineties R&D on energy conservation draws the largest budget. Assessing the specific budget for energy conservation becomes more difficult because objectives for energy efficiency and conservation increasingly are integrated in generic research programs for example for industry and the housing sector. Public spending on renewable energy also increases in size and becomes the second largest recipient at the end of the nineties with public expenditures for renewable energy of around 60 million guilders in 1999 and around 90 million guilders in 2000 (Ministry of Economic Affairs, 1999c). In 1996 the Dutch government announced a CO_2 reduction plan in order to reach targets for reduction of CO_2 emissions with a budget of 750 million guilders from the 1997 national budget (TK,1996).

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[41] Translated from Dutch from the Volkskrant of May 10th, 2000: 9. "De enige energiebronnen die voor lange tijd beschikbaar zijn, zijn steenkool en atoomenergie. (…..) Nederland richt energiebeleid op lange termijn op uitdovende bronnen olie en gas, terwijl het nu zelf de bronnen uitdooft die op de lange termijn wel voorradig zijn".

Table 3.7 summarises development in public funding of energy R&D.

Table 3.7 Developments in Dutch energy R&D, 1970-2000

Time period	Major landmarks	Dominant energy policy issue	Dominant energy R&D direction
Until 1974		Meeting growing energy demand	Nuclear energy
1974-1979	First oil crisis	Safeguarding electricity supply	Nuclear energy
1979-1989	Second oil crisis	Diversification and energy saving	Coal & nuclear energy
1989-1998	Chernobyl accident, Brundtland report, NEPP 1, Electricity Act	Energy saving	Energy saving, emission reduction
1998->	Kyoto, EU, Electricity Act	Climate change	Renewable energy, CO_2-reduction

Three large research institutes have, throughout the years, been responsible for a dominant share of public funded energy R&D[42]. Figure 3.10 makes clear that ECN, KEMA and TNO had a joint budget of around 240 million guilders for energy R&D in 1993. For ECN and TNO the main part of this budget was public funded, for Kema funds are mainly provided by the electricity supply sector. In comparison, the budget for energy R&D at universities is estimated at 45 million guilders in 1993. Core activities in energy R&D at universities concern electricity (distribution, transmission etc.) at the technical universities of Delft and Eindhoven, and renewable energy sources at most universities.

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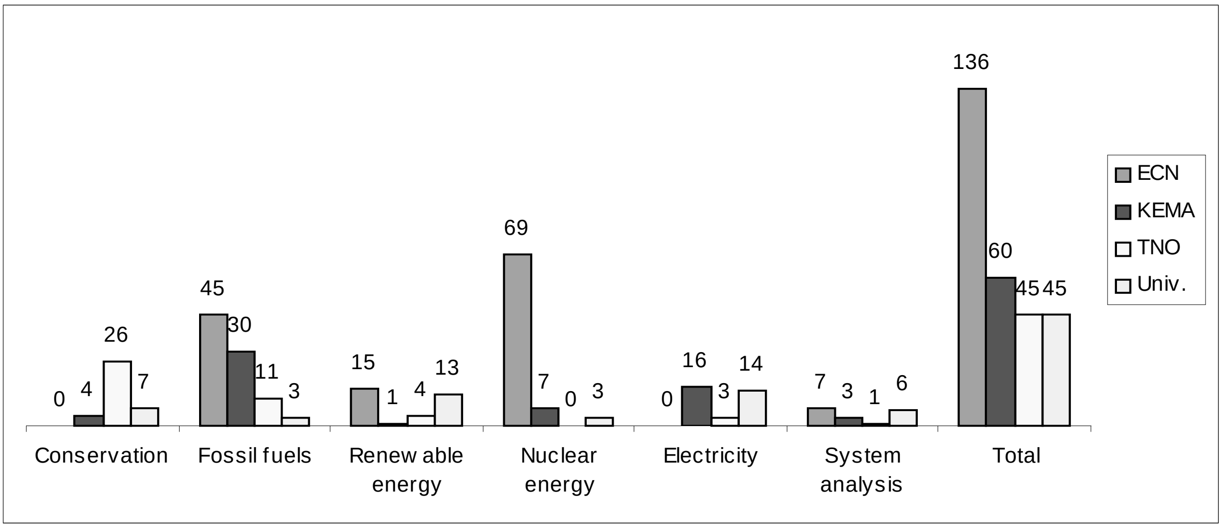
42 This section draws on data from Weijnen (1994).

Figure 3.11 Energy R&D expenditures in 1993 of ECN, KEMA, TNO and universities.



Source: Weijnen (1994), pages 41 and 45. Totals for Kema and Universities do not add correctly because of rounding off of figures for separate energy fields.

Until 1998 it is estimated that the total energy R&D of roughly 600 million guilders annually in the nineties is split in 300 million guilders from both the private and public sector (Ministry of Economic Affairs, 1998). The process of liberalisation, especially since the new electricity Act of 1998, has reduced energy R&D efforts in the electricity supply sector. Previously, the SEP was actively involved in technological development through the research institute Kema and through contracts to institutes and universities. Examples are the gasification plant Demkolec, the development of clean-up technologies for coal-fired plants and a high efficiency gas-fired gas turbine power station at Eemshaven. The innovative approach of SEP influenced the Dutch R&D infrastructure positively, the disintegration of the SEP has reduced R&D efforts since individual production companies are not focussed on long term potential of research efforts but on economic survival in the short term (Veringa, 2000).

3.8 Fossil based alternatives to the central station electricity model

3.8.1 Expansion of combined heat and power generation (CHP)

Combined heat and power generation implies the application of technologies for both heat and electricity production. Historically, it is an important concept as in the early stages of development of the electricity system industries mainly generated their own electricity in combination with heat through steam turbines. In 1950 industry produced 35% of its own electricity and only 5.3% of total energy consumption by industry was met by external electricity (Buiter & Hesselmans, 1999: 19). From the fifties on public utilities started to dominate electricity production and the share of self-generated electricity by industry dropped to 23% in 1969. This trend was reversed by the emergence of the gas turbine which was very well suited to meet combined heat and power demand in industry. Application of CHP with gas turbines started by industrial companies during the sixties. The first period of development shows usage of available technologies at that time (see table 3.8).

Table 3.8 CHP-based electricity generation by various technology types in industry (GWh)

	Steam turbines[1]	Gas turbines	Other	Total
1968	5440	100	0	5540
1978	4780	1460	0	6240
1988	2320	7700	360	10380

[1] Condensing, extraction / condensing and back pressure steam turbines
Source: Blok, 1993, pp. 160.

Between 1968 and 1988 industry installed some 1200 MWe new de-central capacity, predominantly gas turbines in combination with a waste heat boiler, some of it by installing gas turbines to replace steam turbines and a minor part being steam turbines (only four in number). According to Blok (1993), chemical industry started investments in relatively large-scale plants (>10 MWe). These first investments were followed by a wave of investments in smaller plants in other branches of industry at the beginning of the eighties. From 1985 on more large-scale CHP-plants dominated again in industrial CHP-investments, and part of these investments replaced some of the older installed capacity. In 1987, for instance, 40 MWe accounted for replacement of capacity installed in 1970. In 1988 about 600 MWe capacity installed before 1968 was still in operation, although the load factor was extremely low (<20%). In 1988 total installed industrial CHP-capacity was 1810 MWe accounting for approximately 14% of the industrial electricity consumption. At the end of the seventies the use of STEG's for district heating purposes started. District heating satisfies residential heat demands by distributing hot water. District heating systems most often use STEG-based technology, which operates in the capacity range from 7 MWe up to 250 MWe and more. Furthermore, district heating systems in the Netherlands use individual turbines, waste incineration plants and gas engines in small-scale, local, systems.

3.8.2 Further downscaling of generation technology

The increase of decentral CHP was largely met by gas turbines from the beginning of the seventies on. Gas turbines were less suited for application in industry with small power demand. The development of gas engines was useful for power demand lower than 1 MW. In 1986 the first gas engines were installed in the Netherlands. Gas engines are in principle similar to truck engines and have similar emissions. In an industrial setting gas engines reach capacities of around 7 MWe. Generally, gas engines are much smaller, in the range of 0,3 to 2 kWe. Gas turbine technology also developed to smaller scale. In 1980 the first industrial gas turbine installation with relative low capacity (3.2 MW) were used for continuous production (Buiter & Hesselmans 1999: 133). Small gas turbines in the range of 0,5 - 1,4 MW were developed since the beginning of the 90s. From 1993 on the first small capacity turbines (< 1 MWe) were installed. Micro turbines of 20 kWe to 150 kWe are currently tested by Gasunie research with an electric efficiency of around 30%. In combination with the use of heat the efficiency could reach 100%. Various demonstration projects are in progress in 2000 with industries using different types of micro turbines[43] (Roggen, 2000).

Recent developments are the emergence of systems that are expected to be applicable at the level of one or several households, often labelled under the heading mini- or micro-CHP. They include the development of more efficient gas engines, gas turbines and fuel cells that can provide heating and electricity for local urban areas. Mini-CHP systems of some 5 kW can provide heating and electricity for blocks of residential buildings, while micro-CHP provides heating and electricity for individual houses. According to a Gasunie researcher, application of mini or micro CHP for communities as a whole can lead to an overall reduction in energy consumption of approximately 25% compared to the conventional system of local heating from natural gas and electricity delivered by central power stations (van Gemert, 1998). Another technology with expected potential is the fuel cell. Fuel cell development is mainly driven by its potential application in vehicles with a substantial reduction in emissions. However, fuel cells are also applied to the combined provision of electricity and heat. Several hundreds of 200 kW fuel cells are since the end of the nineties part of the power supply in organisations in the USA (Mazza, 2000). Diffusion of fuel cells[44] is in the Netherlands is

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[43] Microturbines produced by Capstone, ABB/Volvo and NREC are installed at a brick company, bitumen producer and swimming pool in a demonstration project by Gasunie, Essent and Nuon (Roggen, 2000).

[44] Three types of fuel cells have been under research in the Netherlands, the molten carbonate fuel cell (MCFC), the solid oxide fuel cell (SOFC) and the solid polymer fuel cell (SPFC).

marginal. In 1998 a SOFC fuel cell was installed of 100 kWe of which the heat was used for district heating[45].

Table 3.9 The development of small CHP systems

Technology	Types	State of the art	Efficiency[1]	Costs
Gas engines		Commercial	OE 86 – 90%, EE 32 - 41,9% [2,3]	Dfl. 1018 (920 kWe)[2]
Gas turbines	Mini: 150 – 2000 kWe	R & D		Dfl. 2600 (1050 kWe)[4]
	Micro: 20 – 150 kWe	R & D	OE ~ 100%; EE 18 – 25% for 60 kW_w turbine[3]	
Fuel cells	MCFC	R & D	EE 50 – 60%	
	SOFC	R & D	EE 50 – 60%	
	SPFC	R & D	EE 40 – 60%[5]	Expected Dfl. 1600 – 2400[2]

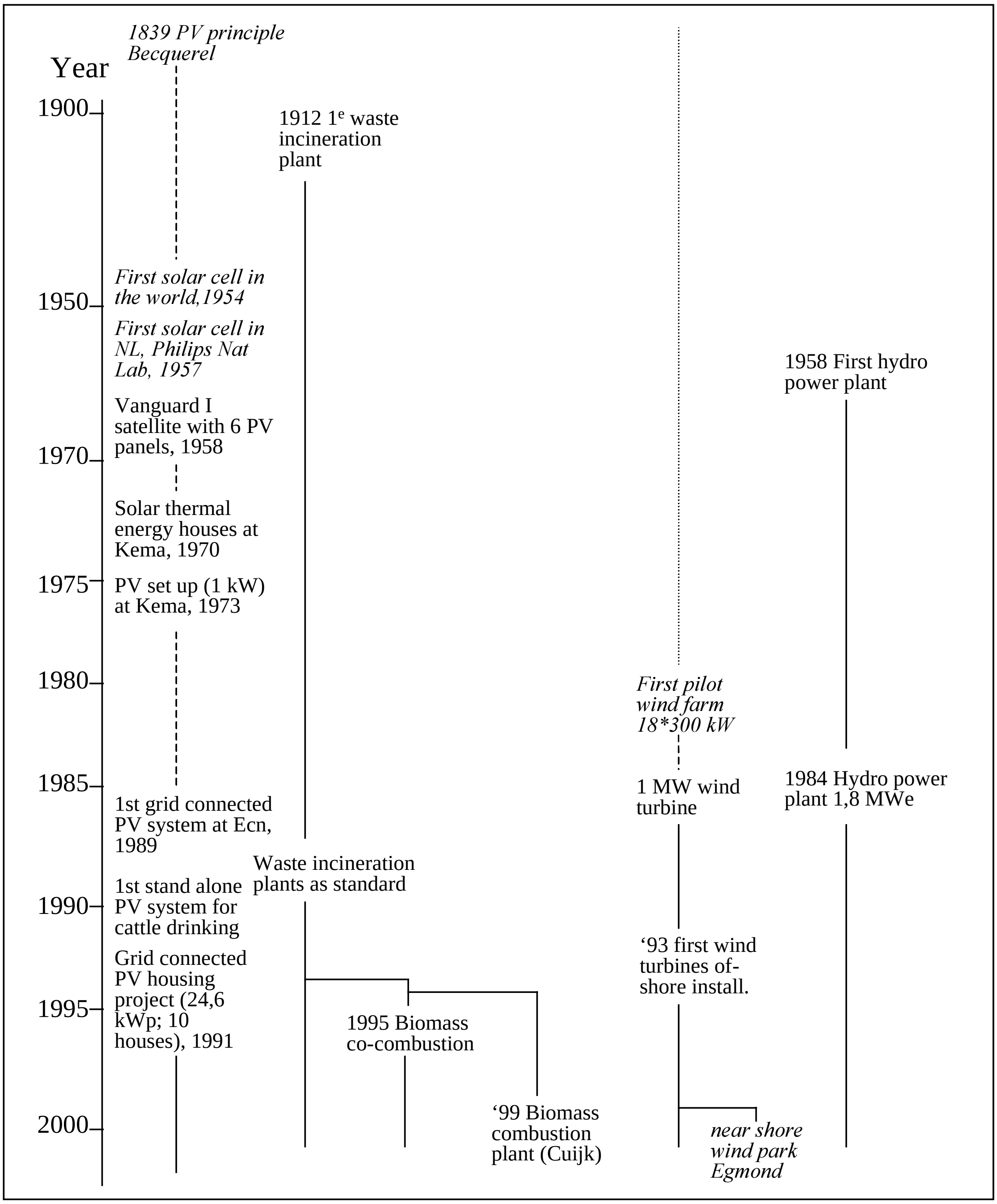
[1] OE is overall efficiency, EE is electrical efficiency;
[2] Dril et al., 1999; [3] Bouwman, W., H. Ruinen, Ontwikkelingen bij 'traditionele' warmtekracht, Hoge asrendementen en voorkamersonsteking', *Gas*, april 1998, pp. 26 – 29.
[4] Van Hilten et al, 1996;
[5] Van der Veer, Brandstofcellen (Fuel cells), in van Engelen, 1997: B1920-31.

3.9 Renewable alternatives to the central station electricity model

This paragraph presents a short overview of technological developments in renewable technologies. The following figure summarises the main developments. Principles for electricity generation with renewable sources are long known to mankind.

[45] In total 200 households could be heated. At that time this fuel cell, manufactured by Westinghouse, was the largest in the world (Press release EnergieNed, 3-6-2000.

Figure 3.12 Technological developments in electricity generation with renewable sources



3.9.1 Wind energy

Until the oil crisis in the seventies wind energy played virtually no role in electricity generation. Some of the applications of wind energy before the oil crisis were focussed on the application in remote areas, especially in developing countries. The oil crisis increased attention for the potential of wind energy as a source for electricity generation in the Netherlands.

In the beginning of the eighties wind turbines were demonstrated in a wind farm of eighteen 300 kWe turbines. In later years the capacity of wind turbines increased to 1 MWe. At the end of 1995 in the Netherlands the 1000 installed wind turbines had a capacity of 250 MW, in 2000 the capacity has grown to around 450 MWe. Energy distributors, private project developers, agriculturists and co-operatives operated the wind turbines. Various plans have been developed from the end of the nineties on for wind turbine parks at off-shore and near-shore locations.

A general development in wind turbine technology is the increase in scale of the turbines, as is shown in the next table. Whereas at the beginning of the nineties the construction of the so-called Goliath wind turbine of 1000 kW was seen as an enormous achievement in terms of size and scale, nowadays wind turbines are planned up to 3 MW or more.

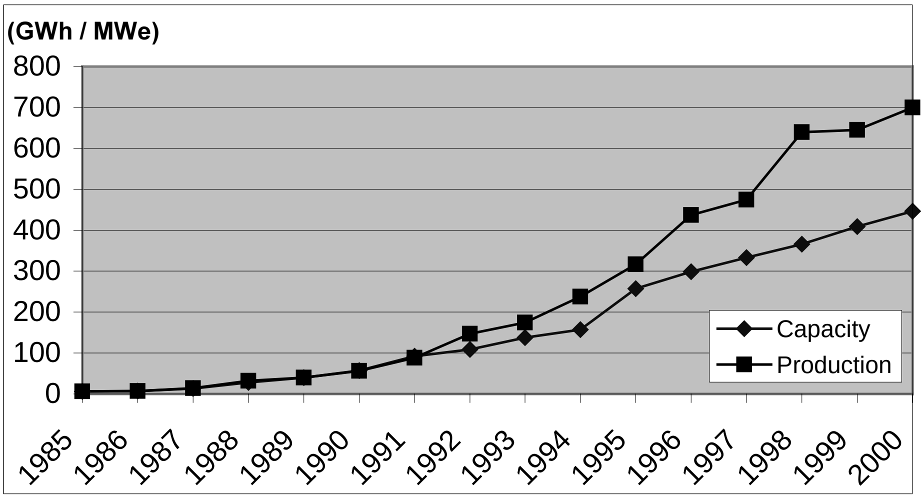
Table 3.10 Upscaling of commercial wind turbines

Year	Capacity (kWe)	Rotor (m)
1980-1983	55	15
1984-1985	75	17
1986-1988	120	21
1989-1992	250	27
1993-1994	400-500	37-40
1995-1996	500-750	40-48
1997-	600-1500	43-66

Source: European Commission, 1998: 104.

Production of electricity through wind energy and installed capacity was rather marginal until the end of the eighties but significant increases were realised from that moment on, see table 3.10. From the middle of the nineties on the growth of wind energy, both in capacity and production terms, has accelerated.

Figure 3.13 Wind turbines, production and capacity



Sources: Joosen et al, 2000; CBS, 1999; PDE website; ECN, 2001.

3.9.2 Hydro power

The share of hydropower in Dutch electricity generation is relatively small in the Netherlands due to the unfavourable conditions for hydropower. In 1958 the first (small) hydropower plant in the Netherlands came in operation (in 1984 extended to 1,8 MWe, Joosen et al, 2000: 7). At the end of the eighties three new plants have been built and total hydro capacity has been steady since 1990 at 37 MW_e. The production of electricity generated with water turbines in the Netherlands is rather constant over the years at around 90 GWh_e (CBS,1999). Further prospects for application of this technology in the Netherlands are limited.

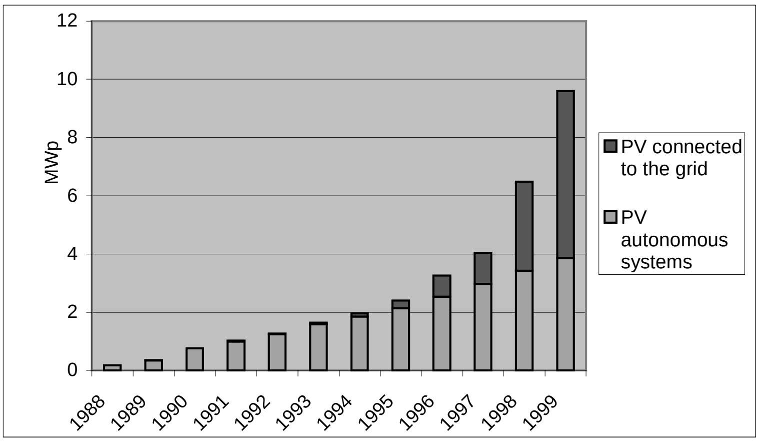
3.9.3 Photovoltaic (PV) technology

Solar energy has a long tradition as a source for thermal heating. The principle of transferring sun light directly into electrical energy is known since 1839, when Edmund Becquerel discovered the photoelectric effect. Scientists of Bell Labs developed the first solar cells in 1954, with an efficiency of 4.5%. The first practical use of photo-voltaic technology took place in 1958 when the first PV powered satellite was launched (Kruijsen, 1999). In the Netherlands the first solar cells were developed in Philips' Nat Lab in 1957. For PV technology distinctions are made in the PV cells and other components (such as inverters, roof constructions). The distinction of PV cells is based on the material used for to produce the cell. The types involve polycrystalline silicon cells; silicon films on ceramics; dye-sensitised ("organic") cells and thin film PV cells. Polycrystalline PV cells hold 85% of all world-wide installed capacity in 1997. The other 15% consisted mainly of thin film (ECN, 1998a: 93). Principal lines of

R&D are the improvement of the efficiency of solar cells and the cost-effective large scale production of solar cells (van Koppen, 2000). Efficiency of solar cells has increased from 7% in 1975 to 14% in 1995. Costs of PV modules have decreased more rapidly from 50 $/Wp in 1975 to 3 $/Wp in 1995 (Kruijsen 1999). In 1999 around 160 MWe of PV power were sold world-wide, while the market is growing with an annual 20 to 25 % (Mazza, 2000).

In the Netherlands, the first PV panels were installed in 1988. The total capacity of these first panels amounted 175 kWe (CBS, 1999). PV technology can be applied in two major configurations, the PV panels connected to the grid and the PV panels as autonomous systems. Early development of PV technology was mainly driven by application in stand-alone systems (Sinke, 2000). This is illustrated in figure 3.14. The development of the AC module (inverter) in 1994 facilitated diffusion of PV systems connected to the grid. An inverter makes it possible to alter the DC current of the PV panel to AC current that is used in the electricity grid. The development of an integrated AC inverter, a so-called AC module, made it possible to plug a whole PV system into the grid. Because no additional inverter has to be installed, installation of a PV panel is easier and malfunctions decrease (ECN, 1995). This technological development of the whole system made it possible for consumers to install their own PV panel without any specific knowledge.

Figure 3.14 Installed PV capacity in the Netherlands



Sources: Central Agency for Statistics, *Dutch energy economy, 1994 - 1997*, 1996 - 1999; Joosen et al., 2000.

3.9.4 Biomass

Until the middle of the eighties application of biomass[46] in electricity generation was limited. Biomass combustion was mainly used for heating purposes. Combustion of biomass in waste incineration plants started in 1912. At the end of the eighties electricity generation in waste incineration plants was commonly applied. In 1992 seven out of nine waste incineration plants produced electricity.[47] Efficiency of the waste incineration facilities has improved steadily, from 360 MWh per ton waste to 600 MWh per ton waste (VVAV, Novem, 1999). Currently, biomass from waste is the main source for renewable electricity generation in the Netherlands.

Co-combustion of biomass (waste-wood) with fossil fuel started in 1995 in the Netherlands. Co-combustion is the addition of biomass to the traditional fossil fuel in a conventional energy plant. The addition of small amounts requires limited adjustments of the conventional coal-fired power plant. Because the biomass burning is CO_2 neutral due to its relatively short carbon cycle, the CO_2 balance of the power plant will improve.

For combustion of biomass special plants can be used. In 1997 the first[48] order to build such plant was given by a distribution firm. The capacity amounted 24 MWe and the proposed fuel was waste-wood. Fixed bed technology was chosen as combustion technology, instead of gasification, because gasification[49] was considered a non-proven technique. The plant came into operation in 1999.

3.9.5 Overview of renewable electricity generation in the Netherlands

The next figures provide an overview of developments in electricity generation from renewable sources. Figure 3.15 shows electricity production based on photovoltaic conversion, wind energy and hydropower.

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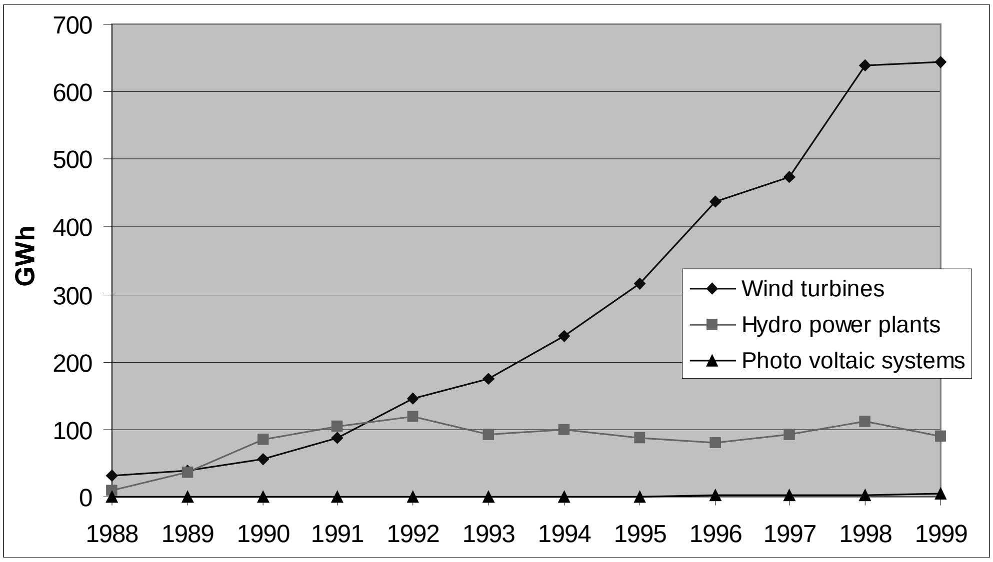
[46] Here, biomass incorporates various types of fuel sources, varying from waste and manure to brushwood and cultivated wood.

[47] Of which four also produced heat for: residential district heating (2), production of distilled water (1) and dehydration of sludge (1).

[48] Some smaller installations, with capacities of less than 1 Mwe, were built between 1997 and 1999.

[49] Gasification is the conversion of a solid energy source into a gas that is burned in a gas turbine. For gasification there are two important techniques in the Netherlands, the circulating fluidised bed technology (for the capacity of ca. 1 to 30 MWe) and the fixed bed gasification technology (for capacity up to 1 MWe).

Figure 3.15 Annual electricity production by three renewable energy sources



Sources: CBS, Dutch energy economy, 1994 - 1997, 1996 - 1999; Joosen et al., 2000

Table 3.11 gives data on electricity production based on renewable energy. Biomass/waste is the dominant renewable source for electricity generation with a share of 77 % in 1999, followed by wind energy with 20%. The fastest growing sources for renewable energy in the period 1990-1995 were wind (a sixfold increase) and PV (a threefold increase), in the period 1995-1999 PV witnessed a much steeper growth (around sixfold growth), while production through biomass and wind both doubled in that period.

Table 3.11 Electricity production from renewable energy resources (GWh)[50]

	Wind	Hydro	PV	Biomass/Waste	Total sustainable
1988	32	10	0.1	817	859
1989	40	37	0.1	821	899
1990	56	85	0.3	882	1024
1991	88	104	0.4	1004	1196
1992	147	120	0.5	991	1259
1993	174	92	0.7	1063	1330
1994	238	100	0.8	1154	1493
1995	317	88	1.0	1224	1630
1996	437	80	1.5	1775	2293
1997	475	92	1.9	2074	2643
1998	640	112	3.5	21971	2952
1999	645	90	5.6	24641	3204

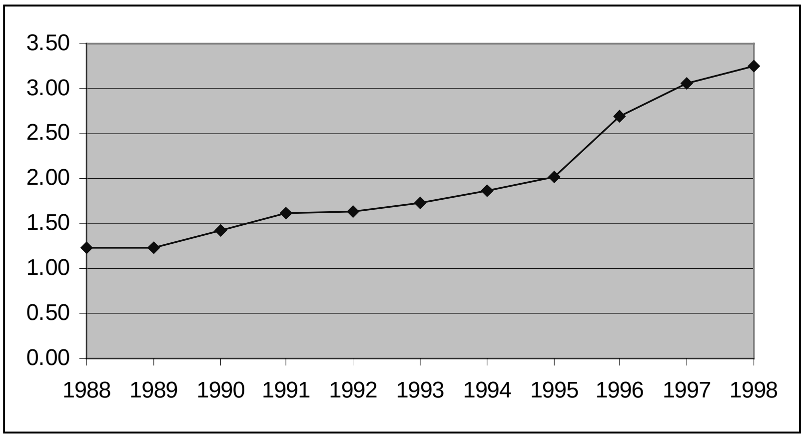
Source: CBS, Dutch energy economy, 1994 - 1997, 1996 – 1999; Joosen et al., 2000

[50] In the column biomass /waste figures of the CBS have been used. In these figures for waste incineration there is no discrimination between renewable and non-renewable waste. The numbers in the last two columns do exceed therefore the real development in renewable energy.

1 Approximately 1240 GWhe (1998) and 1410 GWhe (1999) are from a renewable source. The remainder is the fraction non-renewable input for waste incineration.

Finally, figure 3.16 shows that the share of the national electricity production based on renewable sources increased from 1.2 % to around 3.2% in 1998. In 1998 around 75% of this share was realised through production of electricity in waste incinerators.

Figure 3.16 The share (%) of renewable* sources in total national electricity production, 1988-1998.



* This includes waste, if for waste only the renewable energy is considered the numbers are (estimated) 0.85% (1988) and 2.2% (1998).

3.9.6 The knowledge base for alternatives to the central station electricity model

While the knowledge base for the central station electricity model was extensive and already quite mature (e.g. proven principles and technologies) at the beginning of the seventies, this was much less the case for alternatives to the central station electricity model. The knowledge infrastructure for decentral CHP involved gas turbine technology actors also part of the network of central generators. But knowledge regarding heat demand and distribution and potential applications for CHP with gas turbine technology was still limited in the beginning of the seventies. The oil crisis provide an incentive for more efficient energy use and led industrial actors to increasingly search for alternatives such as decentral CHP. Research on renewable energy sources was started in various universities in the beginning of the seventies and concentrated around work from several pioneers.[51] Much of the earlier work on alternative

[51] Such as van Koppen and Daey Ouwens for PV at the TU Eindhoven around 1972, Smulders at the TU Eindhoven in the same period, van Holten for wind at the TU Delft from the mid seventies on, and Turkenburg at the University of Utrecht. For biomass the organisation 'de Kleine Aarde' was active in promoting use of bioenergy.

energy sources is furthermore started with a focus on application in developing countries.[52] But scientific interest and belief in the potential of renewable sources grew in force during the seventies, illustrated for example by the start of the Dutch branch of the International Solar Energy Society (ISES) in 1976. Nuclear research at universities was still significant but had already fallen from the thrown that was created in the sixties[53] (van Koppen, 2000). Also various organisation were formed that that voiced and channelled concern over the belief (of the electricity sector and government) in nuclear energy as the future energy source, such as the Reflective Group on Energy Policy[54] (Bezinningsgroep Energiebeleid) and the Center for Energy Saving and Clean Technology (CE), which both played significant roles in discussion on nuclear energy[55]. Research on renewable energy also gained momentum through the start of various governmental research programs on wind, solar energy, and later solar PV. Yet the average engineer of that time did not have much expertise on renewable energy as curricula were built on the traditional poles of electrical and mechanical engineering, although some pioneering courses on renewable energy were initiated[56]. Moreover, integration of various renewable sources also demands research with more systems orientation. At the end of the nineties, with significant contribution of renewable sources to electricity generation capacity, some new engineering centres emerge with less focus on the traditional segmented areas of electrical and mechanical engineering and more on systemic aspects of energy supply[57]. It is also reported that the focus of engineering curricula is currently changing towards more sys-

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[52] For example at the University of Twente the Biomass Technology Group (BTG) was founded to develop and transfer biomass energy technologies to developing countries, while Smulders at the TU Eindhoven received funding from development co-operation to develop wind energy in developing countries.

[53] Illustrative is for example the appointment of van Koppen in 1971 at the TU Eindhoven as chair of thermal engineering. Van Koppen succeeded a professor in nuclear energy and decided to give a strong focus to solar energy. This was foremost initiated by efforts from ir. Daey Ouwens (previously involved in PV research at Philips) in his group who convinced van Koppen of the long term perspective for solar energy, also in the light of early signs of the energy crisis (Daey Ouwens 2000; van Koppen, 2000).

[54] Initiated by renewable energy pioneers such as Daey Ouwens, together with Tuininga (from TNO), and Turkenburg.

[55] CE, initiated in 1978 by Potma, provided an alternative scenario in the broad societal discussion in the beginning of the eighties mainly based on reduction of energy use and energy saving, and increases in the use of renewable sources and CHP (Stuurgroep Maatschappelijke Discussie Energiebeleid, 1983).

[56] Early pioneers in education on renewable sources were located at the TU Eindhoven. Around 1977 a comprehensive college cycle of sustainable energy sources was introduced for senior students. In 2000, the course is still running and draws an average participation of around 50 to 100 students each year (van Koppen, 2000).

[57] Examples are centres at for example the Royal University Groningen and the University of Utrecht. Also vocational training of engineers (in Dutch: HBO-opleidingen) has become much more differentiated with for example the choice of tens of specialisations after a basic course of two years (Zewald, 2000). At the technical universities, however, educational curricula are dominantly rooted in the tradition of fossil-fuel and nuclear based electricity generation. However, some initiatives are under way to develop specific engineering curricula on renewable energy principles. At the TU Delft in 2000 preparations have started for a specific engineering graduate course on renewable energy.

tems- and problem-orientation[58] (Heydeman, Veringa, 2000). The development of decentralised and relatively autonomous systems based on a mix of various renewable sources and for example fuel cells or mini CHP are since recently under research by some Ph.D. and graduate students. The same goes for the problems of integrating alternative sources for electricity with conventional sources to the grid.

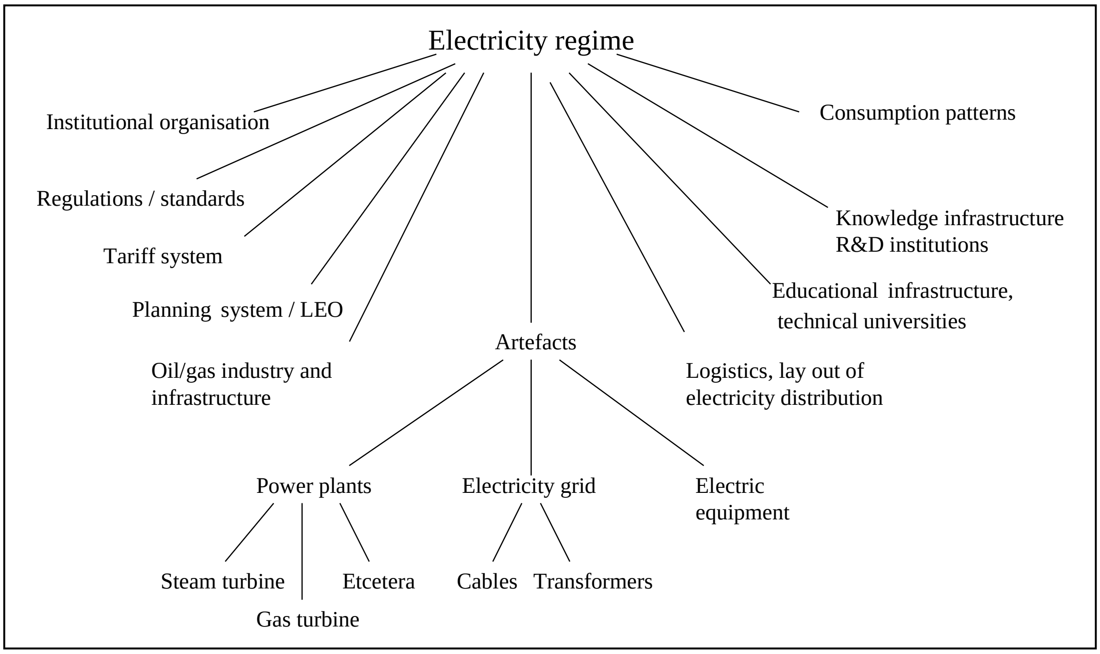
3.10 Overview of the electricity regime

3.10.1 Introduction

The electricity system has evolved towards a large technical system in which components of electricity generation, transmission, distribution and use are integrated and adapted to each other. The system developed along the lines of the central station electricity system and was fuelled by a process of electrification in society. A sociotechnical regime has emerged in which development trajectories of various elements of both a more technological, economic and social nature are interwoven and interdependent. Figure 3.17 illustrates various social and technical elements of the electricity regime.

[58] However, engineering curricula at the end of the nineties still reflects similar segmented fields as those in the seventies and eighties (Heydeman 2000; Zewald 2000). Although basic training has not changed significantly although nowadays students have more options to specialise in for example the renewable energy field in the latter year of their study. Education regarding the electricity system (transmission, distribution, transport of electricity) focuses on basic principles that both apply for centralised and decentralised systems, with a primary focus on the reliability of large-scale centralised systems.

Figure 3.17 Social and technical elements of the electricity regime



3.10.2 The dominant path of technological development in electricity generation

The technological component of the electricity regime is dominated by large-scale fossil based combustion and electricity generation through the use of steam turbines in combination with gas turbines. In the Netherlands gas become the dominant fossil fuel from the end of the sixties on, when an extensive infrastructure for natural gas was developed, with the input of natural gas, less than 1% in 1965, rising to almost 90% in 1975. Electricity producing units are connected to consumers through extensive networks for electricity transport and distribution. All consumers are connected to the distribution network and receive a homogeneous product quality. All elements of the system have in the post war period evolved to a larger scale. Increasing consumption of electricity and increasing electrification has been driven by the continuous availability of electricity, meeting demand at all times, its high reliability, its universal quality and characteristics and its penetration to every inch of the Netherlands. Exploiting economies of scale for units of electricity generation has been a core guiding principle because of the association with increased efficiency. Increasing scale has also been a core guiding principle in the development of the grid. Continuous upgrading and expansion of the high voltage network is associated with higher reliability. Also efficiency can be increased because the most efficient units can be used for base load production.

Institutional arrangements facilitated the development towards larger scale. A basic principle was that all consumers were to be connected to the electricity network, while production companies each served their own region, acting as a monopoly at the regional level and oligopoly at the national level. The existence of relative autonomous producers hampered the employment of full technical and economic dispatch of the system at the national level. Technical and economic dispatch was fully realised with the electricity act of 1989 and the co-ordination by the SEP. Public dominance (and monopolistic organisation) of electricity production and distribution was long unchallenged, and this secured pay back of high investments in the long term. It also enabled production companies to invest heavily in further development of the grid, and to engage in research for example to improve environmental performance of conventional electricity production. Consequently these costs were included in consumer prices. Price competition did not occur, and tariffs were constructed by the producers' association SEP in consultation with government. The economic organisation of the electricity sector also evolved towards larger scale, mainly through mergers that expanded the regions that were monopolistically served by the merged companies.

Competencies of engineers developed along the lines of the electricity system. Engineers are mainly recruited from the technical universities and colleges that have curricula in electrical and mechanical engineering, two fields that reflect dominant clusters of competencies for power plants and electricity distribution. Environmental engineering emerged as an additional cluster in the eighties when environmental demands to electricity production were increasing. In that period also the van Staveren Stichting[59] was founded by actors rooted in the tradition of large scale production and distribution, in order to protect expertise and curricula regarding the traditional fields of electrical and mechanical engineering. Research by the electricity sector is concentrated at Kema, with collective research regularly contracted to universities and research institutes.

Availability, reliability and efficiency have been three fundamental requirements for the electricity system. Progress in steam turbine technology and in central planning, and extension of the electricity network have in the post war period led to continuous improvement on these three requirements. This also strengthened the belief that central production was superior to more decentralised production. Actors that challenged this belief have long been unable to gain footing, especially since a fundamental design principle of electricity production was then under attack. Especially industrial actors, represented by the Vereniging Krachtwerktuigen, calculated efficiency of the system not by solely considering electric efficiency but by looking to thermodynamic efficiency of the system. In the process of designing and extending centralised electricity production, however, electric efficiency always has been the core driving design criterion. In this design, the produced heat was considered as a waste product. When efficiency and environmental pressures started to cumulate due to the two oil crises and increasing environmental attention, the principle of thermodynamic efficiency gained ground. Applying this principle to central electricity production, and the logical outcome of combined heat and power production, proved difficult. Due to irreversibilities in infrastructure (cumulated investments in long distance electricity transport could not be combined with heat distribution) and lay out (central power plants were located far from sources for heat demand), and lack of experience, central CHP projects were not successful. Naturally, also an extensive gas distribution network had already evolved in the Netherlands as the principal source for heat demand. Historically, these systems have evolved in competition, making cooperation and integration virtually impossible (Verbong, 2000).

Gas turbine technology has played a pivotal role in technological development from the seventies on. Initial use of the gas turbine for peak demands improved overall efficiency and reliability of the system. Application of hybrid forms of steam and gas turbines enabled even higher increases of efficiency, thus effectively extending the life cycle of the steam turbine which had at that time reached optimal scale.

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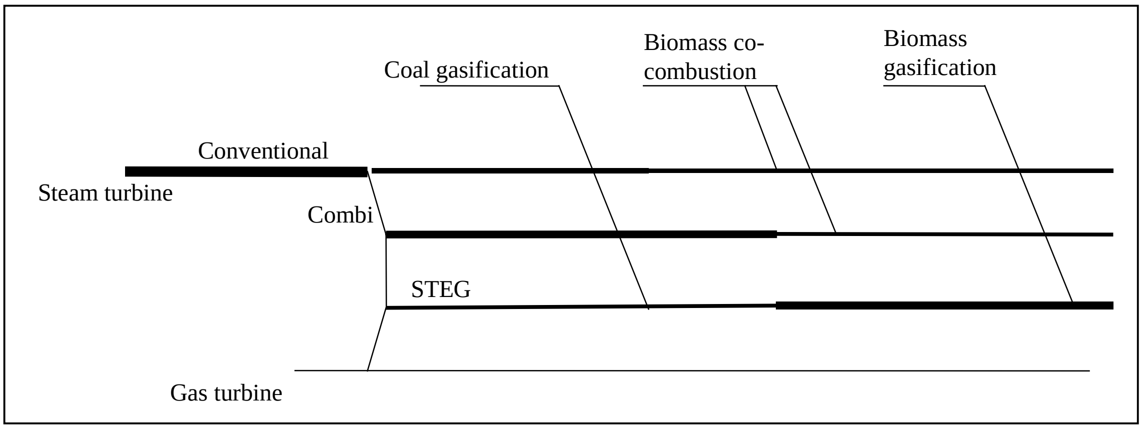
[59] Since the eighties the number of electrical and energy engineers from technical universities and colleges has steadily decreased. In 1986 the 'van Staveren Stichting' was initiated because of concern regarding the continuity of education on energy techniques. Representatives from the electricity sector and industry started the van Staveren foundation to promote and support electrical engineering education. In 1999 chairs in energy technology (UT) and high voltage technique, large scale energy conversion, gas turbine technology, and fuel conversion (all TUD) are supported. New chairs for energy resources economy at the Universities of Amsterdam and Utrecht are in preparation. Participants in the Van Staveren Stichting in 1999 are: electricity distributors (EnergieNed), electricity producers (Sep/TenneT), Draka Kabel, NKF Holding, Siemens Nederland, TKF, Alstom, Elin Holec High Voltage, Holec Middenspanning and Kema (Zewald, 1999).

Figure 3.18 Technological path for electricity generation

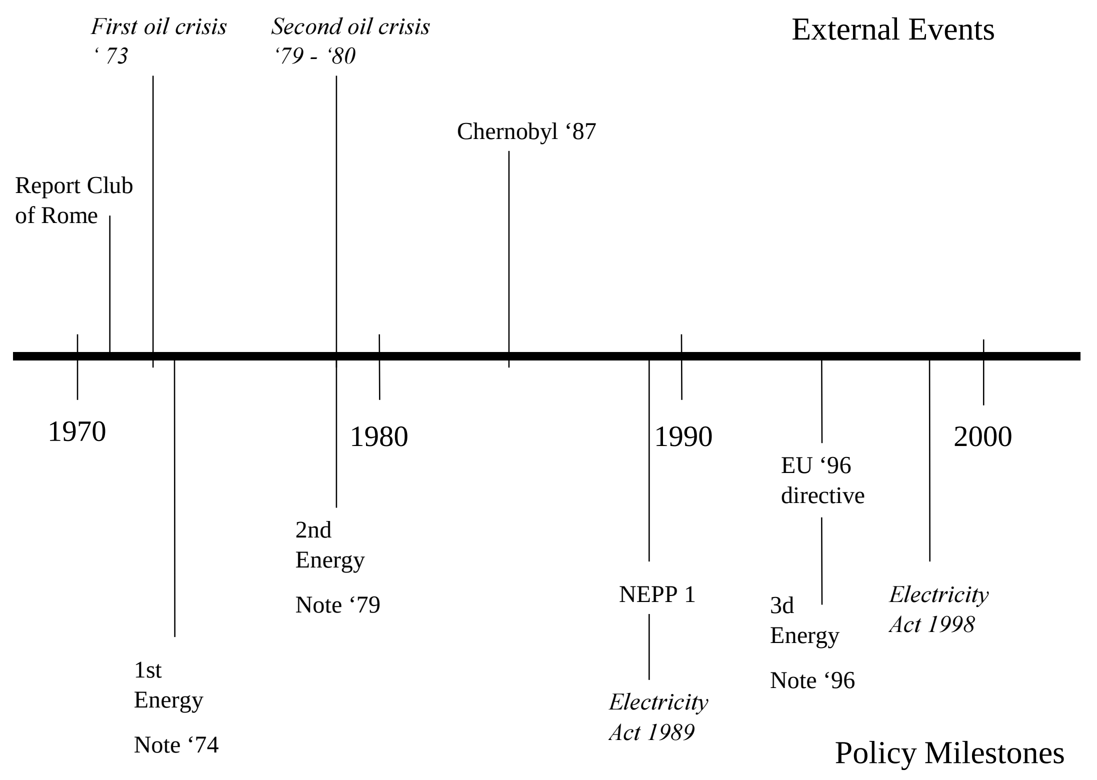


A cycle of scaling up was repeated for STEG technology, while conventional steam turbines were pre-connected with gas turbines. With gas as a fuel source now clearly superior to oil and coal, both in efficiency and environmental terms, technological routes towards gasification were explored by the electricity sector. Figure 3.4. shows initially the steam turbine was the dominant technology in the electricity regime and how the gas turbine has gained dominance through hybridisation with the steam turbine.

3.10.3 Interaction between the sociotechnical landscape, regime and niche-level

In this section we assess main developments in the landscape, the regime and at the niche-level that have shaped the course of the electricity system. Post-war economic growth and fordist modes of production (mass production combined with increasing purchasing power), the electronics revolution and increasing electrification (producing equipment powered by electricity), have been developments at the landscape that enabled, and interacted with, the developments in the electricity system. External events (figure 3.19) have had crucial impacts on directions taken in the electricity regime. Further application of nuclear energy, desired by the electricity sector, has been effectively blocked by the Chernobyl disaster. Political preferences, from strong public involvement in the electricity sector in the seventies to increasing reliance on market mechanisms in the nineties, have had huge impacts. The separation of the previously integrated functions of production and distribution in different companies by the Electricity Act of 1989 created competition within the electricity sector, corroded previously stable actor constellations, and created new social networks. Processes of liberalisation and privatisation initiated by the Electricity Act of 1998 as part of a process of European convergence set in motion developments that at this moment are difficult to assess.

Figure 3.19 External events and policy milestones



At the meso-level, the electricity regime has been shaped on the basis of the development of a central planned large-scale system. Long term planning mechanisms were developed, investments were taking place against the background of power plants and networks with expected life spans of 30 to 40 years. Choices were made for mature and proven technologies, thus reducing investment risks by safeguarding yields. The economic organisation of the electricity sector also became more concentrated, driven by increasing capital costs and by efficiency considerations. Until 1989 decision making regarding electricity supply took place in circles of the electricity sector (SEP) vis a vis government (mainly Ministry of Economic Affairs).

Choices for R&D have also been shaped by the belief of large-scale production. Nuclear energy fitted guiding principles of the electricity sector very well, a belief very long shared by most government actors. Renewable energy sources were always looked at with scepticism, because of its limited potential to produce large scale electricity, but also because it was expected to be unable to take a significant amount of base load production, due to its unreliability. What was also clear was that the electricity sector considered itself the sole actor with enough knowledge and experience to introduce new alternatives for large-scale electricity production. Both in the case of nuclear energy, wind energy, and coal gasification the sector relied on its own expertise. In this sense, although the sector through collective R&D of the SEP did involve universities and research institutes, the sector operated in a relatively closed R&D arena, with the SEP and KEMA as its main actors.

At the niche-level all new technological options were judged on its possible integration with the large-scale system. To become operational, alternative electricity generation technologies needed to be connected to the grid and produce adequate amounts of base load electricity. Gas turbines served a specific niche and evolved in combination with steam turbines to a technology that became embedded in large-scale configuration of the electricity system. Gas turbine technology also played a crucial role in the hollowing out of the centralised electricity regime. It was also able to deliver high electric efficiencies at lower scale, and industries increasingly used gas turbines from the seventies on to shave peak demand and serve base loads, and, in combination with a boiler on its waste heat, to produce combined heat and power. Other alternatives, such as wind technology, could not adapt to the system, were not able to serve a specific niche, and could not generate adequate electricity for the base load. Although the sector was involved, they were not embedded in its knowledge infrastructure, as the sector did not have enough experience and competency for wind energy, and was not part of the actor networks involved in its development.

Environmental concerns play an increasingly significant role in considerations regarding electricity supply. Early environmental concerns regarding emissions of SO_2 and NO_x could be dealt with by the electricity sector without changing the fundamentals of the technological configuration for electricity production and distribution. Although emissions of CO_2 pose a more fundamental problem to the fossil based electricity regime the basic strategy of the electricity producing companies has not changed. Only alternatives that do not fundamentally change the technological configuration of electricity generation and distribution in the Netherlands are being considered. CO_2 storage is considered a viable option, while co-combustion of biomass and biomass gasification are also applicable without changing the dominance of large scale electricity generation with steam and gas turbines. Both the climate change problem, as a fundamental challenge to the fossil-based electricity regime, and the institutional changes in the electricity sector have intensified the search for alternatives to fossil based electricity production. Wind energy is explored as one of the first options.

4. Inertia and Change in the Electricity Regime, 1970-2000

4.1 Introduction

This chapter deals with developments in the Dutch electricity system in the past 30 years in order to look for specific patterns of change that have taken place. The first chapter introduced the co-evolutionary perspective central to this research. This chapter draws on this perspective to explain inertia and change from this perspective. Paragraph 4.2 further outlines the co-evolutionary framework that will be used in this chapter.

4.2 Technological regime

The concept of regime is central to the co-evolutionary perspective used in our research and is defined as follows:

> "A technological regime is 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". (Rip and Kemp (1998: 338)

The development of the Dutch electricity system has taken place along the features of a technological regime as defined above, a regime that has increasingly become dominant. Chapter 2 has shown that a number of fundamental principles form the backbone of the electricity regime. In chapter 3 we have described several important aspects of the electricity regime such as the technology, institutional organisation, and the structure and organisation of electricity consumption. In this chapter we use the concept of regime as a framework for the analysis of development patterns in the past thirty years. This chapter traces and analyses these development patterns, whereas the next chapter explains these patterns.

One of the core hypotheses of the co-evolutionary perspective is that technological changes are being led and guided by the technological regime that is dominant within a sector or domain, and that changes are cumulative, or, in other words, are built on past achievements (see chapter 1 of this report). The cumulative nature leads to technological changes being inclined not only to follow the dominant path, but also to reinforce this path and the dominant re-

gime.[60] This explains why it is difficult to change the nature and direction of technological renewal within a domain or sector. The dominant regime will after all foremost initiate innovations that reinforce the current regime. The decisions and actions of actors, as well as financial means, organisations and structures, are all interwoven with and part of the dominant regime. The dominance and strength of the regime warrants that 'external' technological alternatives have almost no opportunity to penetrate the dominant regime.
Against this briefly sketched analytical background this chapter analyses the developments in the past thirty years in the Dutch electricity system. We start with a short sketch of the dominant regime at the start of our research period. Next we will trace important technological and institutional developments in the period 1970-2000.

4.3 The dominant regime in the early seventies

This section pictures the state of the art of dominant regime in the early 1970s. We distinguish between the technological and institutional setting of the regime and the dominant beliefs and expectations in the electricity regime.

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 electricity industry had its own R&D organisation with Kema in the center and various connections to Dutch 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 the SEP, but a nationally coordinated 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

[60] In economic oriented evolutionary approaches this is explained by increasing returns to adoption.

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.

Beliefs and expectations

At the beginning of the seventies beliefs and expectations regarding the future of electricity supply are dominated by nuclear technology. This fitted well in the timeframe of that period. Around the world the dominant belief was that nuclear technology gradually would 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). Next to nuclear research R&D in that period was focused on the development and improvement of fossil based technologies. Nuclear technology is considered to be the only serious alternative to fossil based technology. The belief in a nuclear future was high. 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. 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).

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.

4.4 Patterns in the development of generation technology

The next sections analyse several important technological developments that take place in the period 1970-2000. Energy saving policies that were introduced after the oil crisis have played an important role in these developments. Relevant are the following patterns of technological development.

4.4.1 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 in its application to jet engines. Extensive R&D efforts in the military-industrial complex paid off in developing more powerful gas turbines with abilities to deliver power quickly. Several companies who had been involved in the development of the aircraft turbines for military jets and also had expertise in the field of steam turbines were able to "adapt and market the uses of the gas turbines in other economic activities" (Islas, 1997: 55). From the end of the sixties on gas turbines are introduced in electricity generation in the Netherlands.

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

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

The specific Dutch role in the development of the gas turbine is limited. Although shortly after the war a Dutch Gas Turbine Organisation was formed through the initiative of the Ministry of Economic Affairs[61] the company only survived a limited time through early applications of the gas turbine in the oil sector and in ships. Gas turbines were useful for stand-alone applications with electricity generation units of 1 up to 25 MW. For smaller capacities diesel engines were more useful, for larger capacities the steam turbine was superior. In the sixties one Dutch company, Thomassen-Werkspoor, still constructed and supplied gas turbines, based on the technology of the US company Westinghouse that had licensed the design (Verbong, 2000).

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

[61] The Nederlandse Gasturbine maatschappij was formed in 1947 by Stork, De Schelde, Werkspoor, Wilton-Feijenoord and RDM (a combination of machinery producers, steam turbine producers and shipbuilders because at that time gas turbines were mainly applied in ships and at oil platforms). At that time the Ministry of Economic Affairs was called the department of technical and economic issues (Verbong, 2000).

turbine started to stagnate, to restructuring of the combined cycle, in which the gas turbine finally became the principal component".

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

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 Dutch electricity chose to apply combined cycles and STEG 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.

The penetration of hybrid forms of gas and steam turbines did not change the basic technological configuration of the electricity system as a whole: centralised, large-scale, fossil-based electricity generation, with high voltage transport and low voltage distribution to customers. However an additional characteristic of combined cycles were the opportunities for application of heat. This was particularly interesting in the light of energy saving policies and government actively stimulated heat distribution projects. The electricity industry was less enthusiastic regarding heat distribution, among others because it reduces electrical efficiency and because it implied large investments in terms of heat infrastructure[62], but was pressured by government to develop this new technological path. However, large scale district heating was never 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, and this led to
- 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;

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

- Distant heating suffered from negative consumer image.

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

The next sections focus on other technological routes that have been explored by the dominant actors in the regime. This includes the nuclear route and the further development of coal technology.

4.4.2 The blockade of the nuclear route

Although nuclear power only has played a minor role in actual electricity generation in the Netherlands, with two relatively small nuclear power plants built in 1968 and 1973, major research efforts were devoted to it. A changeover of electricity generation towards nuclear energy was perceived as a logical step in the sixties and seventies based on the expectation of scarcity of fuel sources, a strong belief in the potential of nuclear technology, and its excellent fit in large scale, long term, continuous electricity production. These beliefs were at that time shared by both the electricity sector and government actors. Until the set up of a societal debate on energy supply other actors were not represented in decision making. Because the Chernobyl accident catalysed societal resistance to nuclear power it was decided to postpone construction of nuclear plants, later changed into a final decision.

Literature on the development of nuclear energy in the Netherlands is extensive and we summarise here some of the main conclusions[63]:

- Dutch government implemented an active R&D strategy for nuclear energy, and pursued the development of a national industry;

[63] A more detailed overview of nuclear energy development in the Netherlands is given in appendix 1.

- The electricity sector was interested in the implementation of nuclear energy as a proven, mature technology, and had no interests 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;
- 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 makeable;
- 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 the dominant regime still has high expectations of nuclear energy until after Chernobyl.

In conclusion the expectations with regard to the uptake of nuclear energy in the dominant regime were high. Actual developments have however taken a very different turn than was expected in the beginning of the seventies.

4.4.3 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[64], a coal research plan is set up to develop new coal 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[65] was developed by several oil companies[66], 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 producers of the gas turbine, Siemens, invested tens of million guilders to improve its operation. The Buggenum plant, that became operational in the middle of the nineties, the first and largest coal gasification plant for electricity generation in the world at that time, and is considered technologically unique (Böttcher, 1999). After a demonstration period until the end of 1997 the power plant becomes part of electricity production by the SEP. In the transition period to a liberalised market, it becomes clear that the plant is not competitive due to the high invest-

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[64] 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).

[65] 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).

[66] 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).

ment costs.[67] As the plant is financed collectively by the power producers (SEP) the plant is considered to be among the stranded costs.[68] However, 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[69] (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[70] 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 CO_2 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 is also due to the strategic interests seen by a leading gas turbine producer in participation 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;

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[67] 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 2 billion guilders or 2800,- guilders per kW capacity (Zon, 2000).

[68] SEP will be dissolved due to liberalisation and privatisation and currently, the Buggenum plant is for sale.

[69] 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.

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

- 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 is seen as one of the most advanced examples of energy technology; it is now economically labelled under stranded costs, this also signifies the change of electricity production from mainly technologically 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 previous developments were mainly initiated from within the dominant regime, also several developments are initiated outside the dominant regime. The first is decentral combined heat and power production and the second is the development of renewable energy.

4.4.4 Combined heat and power production[71]

Centralised electricity generation was at its peak in the sixties of seventies when the share of private, decentral production of electricity reached historical low levels of 19 % in 1968 and 10 % in 1978 (Blok, 1993). The search for higher efficiency and energy saving measures initiated by the two oil crises however strengthened the interest in combined heat and power generation. After the oil crises CHP was the only available short-term alternative to save energy. Combined with a number of factors this led to an uptake of decentral electricity production from the end of the 1980s on, and decentral electricity production increased from 15 % in 1988 to 22% in 1994 and 31 % in 1997 (Arentsen et al, 2000). Several factors explain the fast expansion of decentral CHP:

- Gasturbine technology had become efficient and available for medium size CHP capacities[72];
- Legal opportunities to produce decentral CHP were expanded;
- Distributing companies engaged strongly in decentral CHP as a means to compete with the central producers, also by creating coalitions with industrial companies to get around the installed capacity limit of 25 MW;

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71 This section is mainly based on Arentsen, Hofman and Marquart, 2000.
72 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 CHP;
- The obligation for distributors to purchase surplus electricity delivered to the grid by decentral CHP installations for a reasonable price;
- Both industry and the distributors committed to specific environmental targets regarding energy efficiency and CO_2 reduction through voluntary agreements with government, CHP was a major instrument to reach targets agreed in the covenants;
- The development of a policy package to stimulate CHP (investments subsidies, fiscal measures, attractive gas tariffs and remuneration tariffs) in combination with the set up of a specific CHP-office (PWK) that supported and promoted these measures, thus streamlining the multitude of programs, subsidies and tax measures.

Thus, a combination of factors and measures led to a boom in decentral CHP basically because it became economically attractive for various companies and organisations to invest in CHP equipment. What is especially of our concern is that previously accepted principles and established actor constellations were being challenged. The question of ‘what led actors, and government specifically to advance decentral CHP with so much rigour at that time?’ is crucial because this period visibly marks the beginning of corrosion of the belief in the centralised mode of electricity production. It also marks a change of the previously more or less closed arena of decision making on electricity production and planning towards a more open and differentiated arena. In the ‘tension’ between centralised and decentralised electricity production, apparent in the electricity system from its outset, the strong belief in superiority of centralised electricity production weakened. Two actor groups were increasingly challenging this superiority. In the first place industry, and especially those industries engaged in electricity generation for in-house use, organised through the Vereniging Krachtwerktuigen. Already in the fifties VKW argued that combined heat and power production could reach efficiencies up to 70 %. The general opinion of public electricity producers was voiced by director Vos[73] 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

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

industry became more organised[74] and increasingly were recognised as a significant industrial interest group[75]. The emergence of natural gas and the development of gas turbine technology increased opportunities for industrial CHP. Secondly, government actors increasingly challenged the efficiency of centralised electricity production. There was growing consensus that the monopolistic organisation of electricity production and distribution facilitated inefficiency and slack[76], and that government needed to increase control over electricity planning. Also, there was a growing belief that combined heat and power generation could realise substantial energy saving. Early efforts concentrated on implementation of central CHP[77] through large distant heating projects, but were not very successful.

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

Table 4.1 shows the strong expansion of electricity production by distributors and various industries in the period 1990-1997.

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[74] For example, in 1957 VKW became member of FIPACE, the international organisation of industrial electricity producers. FIPACE was established in 1954 by West European industries because of commercial barriers enacted by monopolistic suppliers of electricity (Buiter & Hesselmans, 1999).

[75] 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.

[76] 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).

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

Table 4.1 Total de-central CHP production by sector (GWh)

	Waste incineration	Energy distributors	Food industry	Paper industry	Chemical industry	Other industries	Horticulture	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.

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

4.4.5 The rise and development of renewables

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 which led 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 marks the start of a strategic policy for alternative options for electricity generation. Based on recommendation from the newly set up LSEO, 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".

4.4.6 Wind energy development in the Netherlands

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). In comparison in the same time period, the early eighties, a wind energy boom took place in the USA. Here, government was able to create a profitable market for wind turbine producers and especially Danish companies were successful (Van Est, 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 initial belief 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[78]. In 1985 9 MW wind capacity was installed in the Netherlands compared to 911 MW in California and 60 MW in Denmark[79]. Based on several sources[80] the following factors are part of the explanation:

- 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 (Jorgenson and Karnoe, 1995);

78 See appendix 2 for a more detailed overview of Dutch wind energy development.
79 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).
80 Gipe, 1995; Wolsink, 1996; Verbong 1999; Smulders 2000; de Keijzer, 2000; Beurskens, 2000.

- 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 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 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 finding appropriate sites and implementation at the local level.

Sexbierum wind farm

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[81] (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 the 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.

[81] 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 has increased momentum for wind energy.

Figure 3.13 in the previous chapter shows that both wind energy production and capacity has grown rapidly in the last ten years. 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, pp. 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 increases. According to van Zuylen (et al, 1999, pp. 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. Potential investors in wind energy hesitate to invest and as an effect the growth in new installations decreases. 1995 turns out to be the year with highest increase in wind energy capacity (100 MW) what is twice as high as in the years to come. Currently, the shortage of locations for wind energy is considered to be the main problem hampering wind energy development and introduction (Ministry of Economic Affairs, 1999c). 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.

Actors involved in implementation of wind energy were energy distributors, private project developers, agriculturists and co-operatives. But of all actors involved the distributors were the most important through the years in terms of ownership. 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). The distributors, after the split up of the sector in 1989 legally able to operate generation capacity below 25 MW, considered wind power a possibility to generate electricity of their own. This was fostered by means of a by government approved levy (MAP-levy) on all electricity which financed a part of the capacity. In later years the concept of green electricity stimulated the installation of wind turbines[82]. The role of the co-operatives has become very small, hardly any new wind turbines have been installed by them (Mulekom, 1999, pp. 13).

Implementation of wind energy is still short of the ambitious plans of 1000 MW in 2000 that were announced in 1985. The main barrier for further uptake of wind energy is the shortage of wind locations, often due to the difficulty of obtaining sites through legal procedures and the objections that are raised. Also while ambitious targets were set by the national government, lower governmental have not felt responsible for implementation. In order to improve this an agreement was reached with the provinces to stimulate uptake of wind energy, which was rather unsuccessful, because it ignored the primacy of municipalities in assigning appropriate sites. Several further initiatives are taken to escape the deadlock with regard to siting. They include offshore siting and establishing administrative agreements with municipalities for uptake of wind energy.

The major issues at the end of the nineties regarding wind energy can be summarised as follows:

- Focus on a large scale off shore wind park with capacity of over 100 MW and individual turbine capacities of 3 to 5 MW;
- Initiatives of environmental group to point out suitable locations for wind energy;
- Increasing demand for wind energy, however shortage of locations for wind turbines;
- Ongoing discussions regarding the ‘environmental aspects’ of wind turbines: especially horizon pollution, noise, and nature (birds);
- Technology develops rapidly for the construction of large scale wind turbines with capacity of 1 to 3 MW. This market has become dominated by foreign companies, only one producer of rotors has a significant share in this large scale market. The market for wind energy at the end of the nineties grows steeply in especially Germany due to profitable compensations for produced electricity.
- Recent studies in a number of municipalities indicate that the attitude of the majority of citizens towards wind energy in general is positive.

[82] Although for green electricity it is not necessary that the distributors owned the wind turbine, the additional income could be used for investments in wind power.

4.4.7 The development of photovoltaic technology

PV technology at the end of the nineties is characterised by the parallel development of various concepts. Some concepts are commercially applied such as the multi-crystalline PV module, but most are in a more fundamental research phase (Sinke, 2000).

Table 4.2 provides an overview of landmarks in PV development in the Netherlands.

Table 4.2 Landmarks in PV development[83]

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, cells produce electricity for eight years
1963	Sharp Corporation succeeds in producing practical silicon PV modules
1970	KEMA starts research on renewable energy (three solar cell houses at KEMA grounds)
1972/73	TUE starts with research on PV by researcher C. Daey-Ouwens (transferred from Philips)
1973	PV system (1 kW) of Philips panels (French make, also elsewhere applied) 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
1980s	Holecsol produces semi crystalline PV cells (van Solingen), with license from Solarex (USA)
1980	Kema builds solar panel for hospital in Tanzania (as part of development aid)
1980	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)
1986	Collaboration Amolf with Holecsol continued in collaboration with R&S Renewable Energy Systems (now Shell Solar Energy)
1985-90	KEMA reduces PV research and focuses on standards and testing of PV panels
1980s	Solar energy activities started at Ecofys in Utrecht
1988	Stand alone PV house in Castricum, 2.5 kWp
1988	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)
1994	All electric zero energy house with 3.3 kWp
1994/1995	Consultancy platform PV is formed

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

1995	Housing district in Nieuw Sloten with grid connect PV 250 kWp, Energy company Amsterdam/Ecofys/others
1996	First professor in PV technology, prof.dr. Sinke (ECN) part-time professor PV physics and chemistry of thin layers at the University of Utrecht
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)
1997/2000	1 MW PV project at Nieuwland (REMU, Ecofys, Novem, EU, a.o.)

Universities have been important actors in developing the fundamentals of PV, later on research institutes became involved in developing and applying PV. Industry plays a limited role in PV development, the main actor is Shell Solar which produces PV modules in its facility in Helmond (Sinke, 2000). 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). Grid-connected PV is not yet an economic alternative and has mainly been applied with government funding because of its potential for the future, its positive environmental profile, its positive consumer image and in order to create learning effects.

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).

Although PV technology has steadily progressed, for example in terms of increased efficiency, there are still several concepts of PV technology in development, it is not yet clear which concept will 'win or loose'. Technological development focuses on two main issues:

reducing production costs of PV modules (using various kinds of materials), and increasing electrical efficiency of solar cells. PV in the Netherlands has developed from the R&D efforts of several pioneers[84] to a significant industry. The role of governmental support in the Netherlands has been crucial both for fundamental research (now for example organic solar cells) and for the various demonstration projects in recent years.

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 visions of pioneers[85], 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;
- 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;
- 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.
- In the nineties the market for PV in the Netherlands (based on PV implementation) has grown at rates somewhat higher than the world-wide average (Sinke, 2000);
- In 2000, production of PV modules is at its peak, mainly because of strong demand in Germany where remuneration for electricity produced with PV is 0.99 DM per kWh;

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[84] In the technological sense, important pioneers were van Solingen who convinced Shell of the importance of PV development, and Sinke who played an important role in fundamental research at Amolf and later ECN, they are mainly responsible for some of the international significance of Dutch R&D (Van Koppen, 2000). R&D and production facilities of Shell Solar are currently located in the Netherlands and Germany, partly because these governments actively support renewable energy (Quote from the director of Shell Solar, W.J. van Wijk, in Roggen, 2000).

Most recently an important policy development took place for photo-voltaic technology was 1997 when the Dutch Ministry of Economic Affairs published its vision on sustainable energy in "Renewable Energy – Advancing Power" (Ministry of Economic Affairs, 1997). In this document, photo-voltaic technology is considered to be the most important option for electricity generation for the foreseeable future. The document also provided that starting point for the set up of a PV covenant between various actors involved in the production and use of PV modules. 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 photo-voltaic technologies competitive as an energy source for the 21st century. Besides technological development, it was also agreed upon that parties have to aim at market development and removal of non-technical obstacles.

The diffusion of solar energy is supported by financial schemes of government (subsidies, fiscal) and distributors (MAP's, green electricity). Governmental rules considering building construction, in which demands for energy performance of buildings are set and exemption of building permits for PV is provided, also contribute to diffusion. The entry into PV development of industrial actors willing to invest (Shell), other actors that generate publicity (environmental groups, governmental bodies that choose the best PV city) or are willing to pay for solar panels (like firms and consumers that are willing to show their commitment) are also supporting the diffusion of solar energy.

As the main obstacles for grid connected PV systems the following aspects are mentioned by the Project Agency Sustainable Energy (PDE, 2000):

- The demand for PV is not structural. All demand is caused by specific projects involving PV. There is also a lack of standardisation of products, actions and information, and of co-operation of actors in the phase of market introduction.
- The costs of electricity from PV systems are too high. Only stand-alone applications are able to compete with fossil based electricity.
- The attitude in the construction industry is conservative, hindering the diffusion of PV in new housing development and on rooftops of existing houses.

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[85] 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).

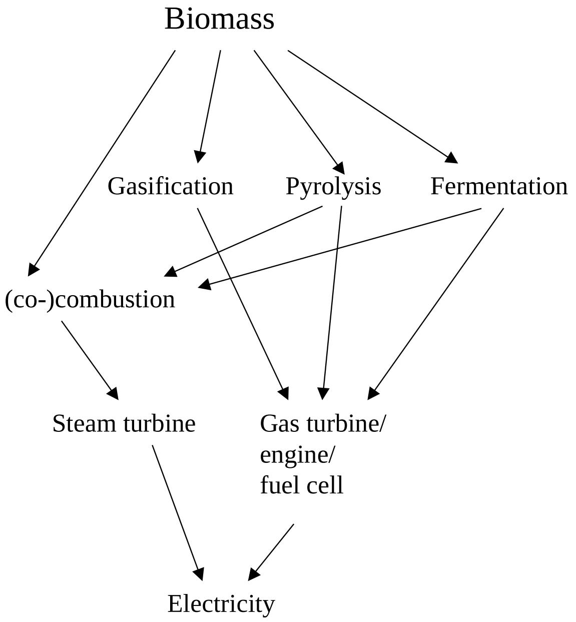
- There are mixed expectations regarding PV. It is regarded an ideal energy source, but its contribution in the electricity provision is and will be very small in the medium term (25 years from now).
- There are no incentives for housing associations (that own a considerable number of houses in the Netherlands), because they do not share the benefits from PV systems.

4.4.8 Biomass[86] emerges as the dominant sustainable variety in the nineties

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 4.1 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.

[86] Here we use the term biomass to indicate renewable sources based on organic material. Naturally, oil, gas and coal are also biomass sources but fossil fuels are generally defined as non-renewable. In this section we also characterise waste as biomass. In initial policy documents this has also been the case, but discussion has intensified whether this is accurate. Currently the non-fossil part of waste is considered as renewable biomass, and the fossil part, such as plastics, is considered non-renewable. EU policy suggests that waste incineration does not fall under biomass, and therefore does not fall under renewable energy.

Figure 4.1 Conversion of biomass into electricity



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 (Ministry of VROM, 1989: 223). Consequently, waste incineration expanded and increasingly electricity generation was added as an additional activity. From 1995 on, electricity production by waste incineration significantly increased (see also table 4.3), 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 is currently the main renewable source for electricity generation (with an 80% share) and is also seen as an important renewable source for electricity generation in governmental plans.

Table 4.3 Waste treatment routes in kg waste

	1995	1996	1997	1998	1999
Compost	1.400	1.500	1.500	1.500	1.500
Incineration	2.900	3.550	4.350	4.550	4.800
Disposal	9.800	8.450	7.400	7.100	7.600

Source: VVAV, website, 2000

Currently, two of the top-three energy distribution companies in the Netherlands have serious business units for waste treatment. The prospects for waste incineration are rather good, since biomass became one of the sustainable energy options in the Netherlands[87]. Next to wind power, biomass is considered a serious option to meet the sustainability goal in electricity supply. In 1999 the Dutch government and the waste incinerators agreed upon a significant increase of biomass capacity with 33% in 2003 compared to 1997. In exchange the Dutch government offered 50% exemption of the REB tariff for the electricity produced. This is supposed to be in line with the percentage renewable biomass in the waste.

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[88]. Know-how regarding fermentation has been traditionally strong at the Agricultural University of Wageningen.[89] The emergence of several programs for biomass R&D[90] 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[91] (Veringa, 2000). At the end of the nineties biomass has become the second largest beneficiary for R&D funding in renewable energy, with 20 million guilders in 1998 and an expected 24 million in 1999.[92] Most R&D for renewable energy went into research on PV.

From the various renewable energy sources, biomass has been the only source also 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

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87 The Netherlands waste policy includes a ‘program for climate and waste’, which comprises a package of measures aiming at reducing CO2 emissions by reducing waste production and other means of waste treatment. The program aims at using 5.1 million ton of waste for energy purposes by 2000.

88 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/.

89 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.

90 The EWAB program (Energy from Waste and Biomass), started in 1989 and is managed by NOVEM.

91 As of 1997 TNO is affiliated with BTG through a significant participation.

92 Overzicht van publiek gefinancierd energie onderzoek in Nederland, 1997, 1998, 1999 (prognose), Novem (2000).

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 box. 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-combustion of biomass, increased efficiency and CO_2 storage in forests.[93]

Co-combustion of biomass in coal fired power plants

Co-combustion is the addition of biomass in a conventional energy plant in small amounts (10 – 15%) as a replacement of fossil fuel. Because the biomass is CO_2 neutral when burned, the overall CO_2 performance of the power plant will improve. The first initiatives involving co-combustion of biomass (waste-wood) originate from 1995 when EPON received a permit to co-combust 60 kilotonnes of scrapwood in its coal fired power plant in Nijmegen. Co-combustion, without a primary conversion step, takes place in a coal power plant. The scale on which co-combustion is implemented therefore is large. Actors involved concern mainly the (former) central producers that are the sole actors operating coal fired power plants. For co-combustion in existing coal power plants investments mainly concern reduction of the volume through grinding of the biomass. Furthermore, efficiency of coal fired power plants is lower when co-combustion is applied (ECN, 1998a). Co-combustion was in 1997 considered a proven technique (Faaij, 1997, pp. 10), but according to the ECN (2000) adding more than 15% biomass in coal fired plants is critical and needs more research. It is expected that this technology will be the second important technology in terms of contribution to renewable energy in the future. Except for the supply and logistics of the waste, the whole process of 'normal' operation of a coal fired power plant needs only small adjustments. Co-combustion of waste-wood in coal fired power plants moreover is more attractive than combustion of waste wood in waste incineration plants because the emission guidelines for waste incinerators are stricter than for power plants (ECN, 1998a). Another positive incentive for electricity production through co-combustion is the fact that the 'biomass' combustion part is considered 'green' electricity, with a zero tariff for the regulatory energy tax (REB) for buyers, whereas regular electricity has a REB tariff from 3.54 to 8.20 cts/kWh (for respectively buyers up to 10000 kWh/yr and 50000 kWh/yr) (ECN, 2000: 58).

In 1999 the Minister of the Environment announced that the high CO_2 emissions of coal fired power plants were unacceptable and that power plants should have an emission profile comparable to gas fired power plants. This demand came down to transformation of the coal plants into natural gas fired power plants. The former central producers, as operators of the coal power plants, opposed the demand because of the high costs of closure (estimated at fl 1 billion a year) as the plants did not have reached the end of their economic lifespan. This would have a serious negative effect on the market position of the central producers. Furthermore they argued that the closure of the plants would lead to an increase in electricity imports of less clean power plants. Moreover transformation to gas fired plants would increase the dependency on natural gas, causing a number of undesirable effects (Press release EnergieNed, October 20, 1999).

Recently an agreement was reached in this dispute by the national government and operators of coal fired power plants to increase the amount of biomass used for co-combustion. In return government changed the fuel tax for generators reducing costs for production. Co-combustion on a large scale (in combination with all possible emission reduction techniques available) makes it possible to improve the CO_2-profile of the coal fired power plants towards a level comparable to gas fired power plants. The goal is to reduce the CO_2 emission in 2010 with six Mton compared to 1990 (this implies a 40% reduction).

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

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;
- There are several routes available to exploit the potential of biomass. In 2000, the dominant applications by the electricity sector are combustion and co-combustion because they are a good fit with the technologies and competencies of the electricity regime, as electricity production with biomass can take place in traditional fossil fired power plants with either steam or gas turbines, albeit with some adaptations;
- The other conversion routes, such as gasification, fermentation, pyrolysis are more driven by actors outside the traditional electricity sector and are considered to have more development potential, some of them are in the early commercial phase;
- Several types of waste are now being considered for electricity production, and their application also depends on their priority as a waste problem. Thus, conditions and developments in order regimes (waste regime, agricultural regime) play a significant role in the development of biomass as an option for electricity generation;
- In some of the conversion routes biomass can have multiple applications. If biomass is converted to bio-fuel it can both serve the electricity 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 has had 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. Also the company Electrable recently announced 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). Thus there is significant uncertainty regarding biomass availability and its logistics. 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. 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 and expectations regarding the application of biomass.

4.4.9 The introduction of ‘green’ electricity as a marketing concept

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. 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. The market was less of a driving force when the electricity sector was still characterised by monopolistic organisation and stability. The companies’ culture changed also because more economists came to occupy key positions in the company, whereas previously management was dominated by engineering background. The increasing market orientation of the energy distribution company explains why the idea of green electricity could emerge.

In 1995 a successful pilot to sell ‘green’ energy was started. Earlier studies had already indicated that consumers were willing to pay a premium for ‘green’ electricity. From 1996 on most large energy distributors offer ‘green’ electricity. Government supported green electricity through exemption of the regulatory energy tax. This tax is imposed only on electricity from non-renewable sources, to close the gap between the electricity price based on fossil fuel relative to renewable sources. In 1996 the result still was that purchasers had to pay more for green electricity than for conventional electricity, but in the year 2000, due to rises in the regulatory energy tax the price difference had disappeared almost entirely. Dutch energy users in 1999 bought more than 350 million kWh of green energy, around 0.3% of total electricity consumption in 1999. But the increase in consumers of ‘green’ electricity is rapid, between July 1st 1999 and January 1st 2000 the growth rate was 47%. For example for Essent the number of green electricity customers expanded from around 50.000 in 1999 to 100.000 in 2000 on a total number of around 2.3 millions households.[94] An important explanation for this rise

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[94] These figures are based on information provided by the WNF for August 1999 (see also Schöne, 2001) and Essent for 2000 (see Essent, 2000).

also lies in the role of the Worldwide Fund for Nature (WNF). As explained in an earlier section their initial role was to verify the authenticity of the renewable sources for green electricity. WNF became also actively involved in marketing campaigns for green electricity because it views climate change as one of the largest threats for nature. In September 1999, when green electricity had become available throughout the Netherlands[95], 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 EZ and VROM, consisted of various advertisements in national newspapers, large scale actions with dressed up polar bears handing out 300.000 application forms and 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 an increase in the monthly growth rate of green electricity from around 2500 to 10.000, and led to a sharp increase in public recognition of the concept of green electricity (Schöne, 2001). The co-operation of WNF with the energy utility also reflects the shifting culture of environmental organisations from one of protest to practical solutions (Hartman, Hofman and Stafford, 1999). In the case of WNF its strategy had shifted from one of fund-raising for nature conservation with a neutral image towards a more active strategy in which WNF seeks opportunities to co-operate with parties in civil society (Glasbergen and Groenenberg, 2001). Apart from being involved in public campaigns to promote the campaign WNF has sought to develop a transparent and accountable control mechanism for green electricity. Its objective is to have a system for green electricity certificates at the European level, with the certificates giving details regarding the origin (which renewable sources), location and environmental profile (related waste and emissions) of the generated green electricity.[96]

4.4.10 Overview of the emergence of renewable energy

After the oil crisis renewable energy is considered as an alternative for electricity generation. Main proponents for the active development of renewable energy mainly originate outside the dominant regime. The development of renewable energy is put on the political agenda by several societal organisations, government and academics. Wind is considered the most promising option for the short term, and government is developing an ambitious R&D plan

[95] At that time also other utilities had adopted the principles of green electricity, although often under other names (nature power, eco-power) because of the trademark of Essent on the name green electricity. WNF promoted the general idea of green electricity and not the specific trademarks.
[96] Currently the association of energy distributors, EnergieNed, is involved in the development of the system of certificates.

that breathes the guiding principles of the dominant regime. After a phase of fundamental research the SEP is involved by government in order to integrate wind energy in the existing electricity system. However, the electricity industry at that time does not consider wind energy or other renewable a viable option.

In the eighties several programs for renewable energy continue, but main R&D efforts are put into coal technology and energy saving. When the climate change problem becomes more apparent, and also energy saving is not able to significantly reduce CO_2 emissions, renewable energy gets a higher priority on the political agenda. This crucial change coincided with the first National Environmental Policy Plan that reinforced the need to save energy. In a follow up to the NEPP specific targets for the reduction of CO_2 emissions were set and this is followed by a policy goal of 10% renewable electricity production in 2020 set in the third White paper on Energy in 1996. Specific programmes to reach CO_2 and renewable energy targets led to a boom of projects in this period. R&D efforts for renewable energy increase, but also the mix of instruments is broadened with increasing focus on the stimulation of demand. The distributors start to take an important role in the development of wind energy and later biomass, also as part of their environmental action plans. Distributors also play a role in the implementation of PV, but here more actors have played an active role. Production companies only seriously begin to consider renewable energy, especially biomass, when the option of closing down coal fired plants is on the political agenda, and actually proposed by the Minister of environment. Co-combustion of coal with biomass becomes an important strategy for producers to reduce this threat. In the last couple of years renewable sources are increasingly developed by distributors because they realise it is a viable segment of the market through the marketing of green electricity, and because fiscal measures start to make green electricity more attractive compared to conventional generated electricity.

4.5 Patterns of institutional change

The electricity industry in the last thirty years has witnessed a process of increasing concentration and increasing scale of companies pressured by the necessity to increase efficiency, both in electricity production and distribution. The electricity act of 1989 enforced a new structure upon the electricity sector in which distribution and production companies were separated, and which created effective national control of the electricity industry. 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 allows for some decentralised electricity production and import of electricity. Distributors were allowed to produce electricity in up to 25 MW capacity plants, industrial companies are allowed to produce unlimited amounts of electricity (Arentsen et al, 1997). The process stimulated increases of decentral CHP to the extent that central electricity planning was seriously affected. The act also initiated increased concentration in distribution, and distribution companies aimed for strong market positions. The change from a monopolistic towards a liberalised model is further implemented with the electricity act of 1998. Production companies have become foremost foreign-owned, and the SEP has been dismantled, with ongoing discussions regarding so-called stranded costs.

In conclusion the institutional dimension of the electricity regime has witnessed fundamental changes. The previous closed and monopolistic organised electricity sector has opened up and is now dominated by the market mechanism.

4.6 Summary and conclusions

- The variety of routes for electricity production has significantly increased in the last decades and especially in the 1990s. At the end of the sixties, the start of our analysis, electricity generation was dominated by fossil fuel fired power plants making use of steam turbines. The gas turbine emerged as a market niche in that period, and its characteristics of flexibility and increasing efficiency turned it into the dominant technology in a period of twenty to thirty years. Moreover, gas became the dominant source for electricity generation, replacing coal and oil, facilitated by the natural gas infrastructure that was constructed after the significance of the gas reserves in the North of the Netherlands became clear.
- Nuclear energy fitted well in the central station electricity system. While the traditional actors in the selection environment (electricity sector and government) were clearly in favour of nuclear energy, developments in the landscape such as increasing environmental concerns and increasing societal resistance to technocratic decision making, and the Chernobyl disaster as an external event, made implementation of nuclear energy difficult;
- Gas turbine technology has transformed the technological regime, now hybrid forms of steam and gas turbines are the dominant technology;

- Gas turbine technology has also paved the way for increasing decentral CHP, due to its positive overall efficiency;
- Gas turbine technology in its development towards smaller scale sets up application at the level of households. Also fuel cells are being developed towards small scale application;
- Variation has long been stimulated through top-down R&D programmes that focussed on the development of options for large-scale electricity generation. For nuclear energy and wind energy these efforts have mainly been unsuccessful, among others because R&D was not embedded in society.
- Renewable energy options have until the end of the eighties mainly been supported because of their technological niche properties, but now are increasingly being implemented because of market niche properties.
- Various renewable options have developed in the period 1970-2000 but implementation has been slow. R&D has long been focussed on supply-push, but market instruments have gained prominence in the last decade. In the nineties an increase in uptake can be witnessed, also because distributors have started to ‘carry’ renewable energy because of their potential as market niche.
- Large scale oriented production companies have not been seriously involved in renewable energy options but have now started to develop biomass co-combustion as a market niche that can serve government demands with regard to reduction of CO_2 emissions.
- Variation has clearly increased in the last decade. New actors have entered the stage of electricity generation, due to liberalisation and the chances given by stimulation of climate friendly generation technologies. Distribution companies are increasingly using renewable energy in their marketing strategy. The production sector has generally not been involved in the implementation of renewable energy, except for co-combustion of biomass in coal fired power plants. Consumers are attracted to renewable energy because of its environment friendly image, such as for ‘green electricity’, or because they are willing to invest in renewable energy, such as for PV, because of other features such as the relative low additional price for a house in combination with its charisma. In the development of renewable options other factors than costs have therefore played an important role, factors that are not part of the selection environment of the dominant regime.

5. Explaining Inertia and Change in the Electricity Regime

The previous chapter sketched the dominant patterns in the technological and institutional development of the Dutch electricity system. This chapter explains these developments in the perspective of the co-evolutionary theoretical framework developed in Matric.

5.1 The dominance of the fossil based electricity regime and the mechanisms for its inertia.

Electrification is one of the greatest achievements of mankind in the 20th century. Electricity has become one of the crucial ingredients for human welfare and the economy at large. The roots of the penetration of electricity in everyday life lie in the early period of the last century. Upscaling and extension of the central station electricity system and its network enabled continuously increasing electricity use, and was facilitated by institutional arrangements. It is our argument that the success of this ensemble of technological, economic, social and institutional developments in the built up and penetration of electricity and the electricity system until the seventies also has created lock-in effects hampering the desired transition towards a less carbon-intensive electricity system.

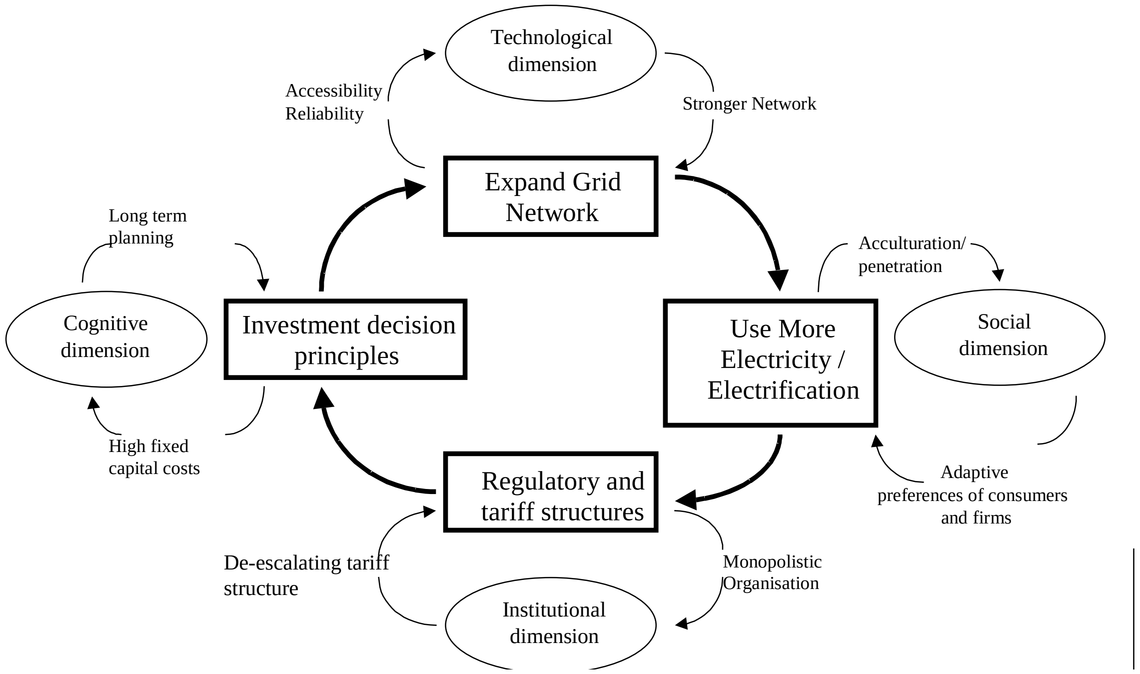
The patterns of interaction that have been created by these mechanisms can be characterised by centralism and closedness/closure. Economies of scale of power plants, the association of larger scale with larger efficiency, and the development of a nation wide high voltage network funnelled institutional developments. From systems with local roots, the core organisational level for electricity production developed towards the provincial and national level. The tendency towards centralisation was also advocated by the national government in its efforts to increase its grip on the electricity sector, and was facilitated by the oil crisis in 1973. The oil crisis reinforced demands for higher efficiency of the system, and higher efficiency was associated by government with a higher degree of organisation in the electricity industry. Centralist thinking has guided both investment decisions and R&D in energy supply. Positive expectations regarding nuclear energy can partly be explained by the excellent fit of nuclear energy in the model of central-station electricity system. The centralist mode of governance is illustrated in the early efforts to develop wind energy as a fit to the design of large-scale central production under the guidance of the SEP.

The central station electricity system, its growth and optimisation, also structured decision making processes. With reliability and security of supply as core guiding principles, and the technological principles fixed to steam turbine technology, the electricity sector has long been a relatively closed community dominated by engineers. Closedness of the electricity sector was facilitated by its monopolistic organisation, and the acceptance of government (and society) that the complexity of electricity production and distribution was to be left to the realm of engineers. Power struggles were mainly occurring between the various producers, and between the sector and the national government. Other actors, and societal concerns (other than unconditional provision) have played a very limited role in the course of the development of the system. Impact of the closedness of the sector is illustrated by the failed effort of government to develop a national nuclear industry, an effort frustrated, among others, by the unwillingness of the electricity producers to co-operate with Dutch industry.

While the two oil crises in the seventies challenged fundamentals of the electricity system, especially unconditional availability, this did not change mechanisms toward centralism and closure because both the expectations regarding nuclear energy and the changeover to natural gas relieved the urgency for other alternatives, such as renewable energy or decentral CHP. Especially the national energy debate regarding energy supply made clear how beliefs and expectations regarding energy supply had diverged between governmental actors (especially the ministry of economic affairs) and the electricity sector on the one hand and the society at large on the other hand. At that time the government and e-sector's perception reflected beliefs of the dominant regime, making their choice for nuclear energy and coal as pillars in energy supply logical because they perfectly fit the technological configuration of the electricity system with large scale connected power plants. Safety aspects, risks and environmental aspects are technical problems that can be solved or kept within boundaries based on risk calculations. The fact that nuclear energy introduces a fundamentally new dimension to risk, due to the magnitude and impact (also in terms of time) of a possible calamity and nuclear waste, makes customary risk calculations inappropriate in the view of various societal groups.

In figure 5.1 main lock-in mechanisms are pictured, based on the earlier chapters and partly inspired by recent work from Unruh (2000).

Figure 5.1 Lock in mechanisms in the electricity regime



Source: Author's observations and Unruh (2000: 826)

Various mechanisms have re-inforced the large scale central station electricity system. The central mechanism is the cycle of investment in large scale of generation units, expansion of the grid and increasing electricity use, facilitated by regulatory and tariff structures and associated with increasing reliability and cost-effectiveness. This central mechanism has been fed by lock-in mechanisms for different elements of the electricity system. The dominant technological configuration in the electricity regime, large scale electricity generation and distribution is connected to a mode of provision of electricity based on the reliable distribution of a technically undifferentiated product to customer groups.[97] The availability and access to reliable and cheap electricity have enabled penetration of both electricity infrastructure and use at the household and industry level. Clearly various industries have adapted to cheap source of electricity by increasingly designing products that depend on electricity as input.

At the institutional level, the development of the regional monopolies of electricity provision is based on the desire for accessible, cheap and reliable electricity for each citizen and organisation. The increase of electricity use is also linked to tariff systems and tax structures.

[97] There is differentiation in tariffs to giant users and households, while also users are charged with regard to peak use. Moreover although the product is delivered homogeneously to customers at 220 volts, in earlier stages the product is transported at different voltages, and also the customers have various consumption patterns.

Energy intensity of Dutch economy has increased in the sixties due to low energy prices and government policy to attract energy intensive sectors such as the chemical industry, also because of the then discovered abundant quantities of natural gas. Regional monopolies made a tariff system possible that secured pay back of investments, such as R&D, because they were passed over to customers. This mechanism also reduced risk of investments in large scale units. A tariff structure was developed with lower prices/taxes for large industrial users. A system that is still in place, with the regulatory energy tax (REB) only applicable for small to medium sized users. Also, at the institutional level, the dominance of the SEP vis a vis government in settling tariff issues such as remuneration tariffs for self-producers led to tariff structures that benefited the further expansion of large scale generation units and the grid.

At the cognitive level, a guiding engineering principle was the association of larger scale with higher efficiency, combined with economic principles of installing power plants with a lifespan of 30 to 40 years. This led to long term planning and investment schemes and reliance on mature, proven technologies. Alternatives were developed and judged based on performance characteristics originating from the regime. The specific technology needed to be altered in a way that it would fit in the dominant technological configuration. In the course of events it was then learned that these alternatives could not meet these requirements (see experiences with the Sexbierum wind park and the wind plan of distributing companies) or did not have a sufficient level of maturity. Competencies of engineers regarding these principles were built up at educational centres and through curricula in line with the tradition of basic principles of the central station electricity system.

The expansion of the grid is interdependent with the development towards larger power plants. A stronger grid can keep the plants interconnected and increases overall reliability of the system, while increasing scale of power plants makes an expanding grid necessary. The grid is designed to transport high voltages of electricity, fossil based electricity generation units are designed to produce these high voltages. Alternative ways of electricity generation need to be configured in order to deliver to the grid.

The introduction of the gas turbine in the electricity system initially did not alter any of these mechanisms. After its successful introduction in the niche of peak production, hybridisation of gas turbine technology with steam turbines extended the life cycle of the mature steam turbine technology. Steam turbine technology had reached its limits (optimal scale / efficiency) in the course of the eighties. In combination with gas turbines, both combi and STEG configurations proved successful in further improving efficiency of the generating units, again facilitated by the development towards larger scale.

The previous mechanisms have also played out in the way changing demands have been absorbed by the sector and government. Increasing environmental demands have been dealt with without changing the fundamental technological configuration of the system. The main routes were the increase of electrical efficiency of power plants, improved logistics of the grid, variation of inputs based on environmental characteristics and availability, and implementation of add-on technologies to deal with emissions.

Also 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.

R&D strategies by the government have long breathed the belief that the course of technological development and diffusion is malleable, see 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 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).

Beliefs and expectations regarding electricity supply now and in the future are also structured by the aforementioned mechanisms. An important belief in the electricity sector is that coal and nuclear energy are sources for the long term future. Renewable energies are not fit for base load production, not yet mature enough, and their small scale does not fit the guiding principles of the dominant regime. This is confirmed by negative experiences with especially wind energy. Furthermore the expectation is that if renewable energies become competitive, they can only serve a small amount of demand. Therefore the dominant focus is on further optimisation of the current electricity system, adapted to the environmental and climate change demand. The focus is on incremental solutions that can keep environmental problems within limits, the belief is that current technologies, sources, can deal with environmental problems. With regard to climate change a strong feeling is that it is not yet proven. Moreover the general feeling is that the reduction goals can not be achieved, and that if real pressure comes CO_2 storage is a good alternative, while it also has a good fit with the potential increased use of coal gasification.

5.2 The dynamics of change: transformations in the regime and the emergence of niches

The previous section illustrated the various mechanisms that explain the inertia of the electricity regime in terms of the dominance of large-scale fossil fuel electricity generation. In this section our argument is that while these mechanisms are still in place and form a part of the explanation of current development patterns, they are increasingly challenged and changed due to various factors at the landscape level, regime-level and niche-level. Central factors that have increased dynamics are at the different levels: increasing use of market mechanisms and liberalisation, and increasing concern over climate change at the landscape level; the penetration of the gas turbine at the regime-level; and the increasing number of actors involved in electricity generation at the niche-level.

The previous chapter showed that a number of important changes have taken place in the electricity regime. Despite path dependencies and irreversibilities, the dominant regime is subject to change and the co-evolutionary perspective gives clues for explanations. Firstly, coincidence can play a role in changes. In electricity supply the reactor accident in Chernobyl has had a decisive influence on the further application of nuclear energy in the Dutch electricity system. Secondly, new (scientific) insights can contribute to regime transformations. Changes in thinking regarding the finity of fossil fuels is an example of this. In the beginning of the seventies the idea of scarcity was central in international energy circles, whereas nowadays the idea of shortage is much less prominent in the energy sector as a whole and the electricity industry in particular. At the time of scarcity the electricity sector was forced to accept strong government interventions with regard to the fuel base of Dutch electricity generation.
Thirdly, sudden non-technological events can trigger adjustments or changes in dominant technologies. An example is the introduction of the market mechanism in the Dutch electricity system that induced new relations between the state and the electricity industry. Fourthly, technological innovations in other sectors or domains of the economy can have consequences for the dominant regime. With respect to this, information technology has contributed to the central management en centralised co-ordination of electricity supply, but also made clear that the monopolised model of the electricity system should not be considered as a natural monopoly. Fifthly, change in the dominant regime can be initiated from within the regime. An example is the gas turbine. This technology improved load management of the centralised electricity supply and reduced costs of centralised electricity production, but also initiated a development towards smaller scale in electricity generation. The smaller scale of generation technology has reinforced the position of self producers in the electricity system. Sixthly, regime change can be explained within the co-evolutionary perspective by changes in the selection environment. Government objectives are an important part of this selection environment. In this chapter we will see that the government has an important initiating role in some changes in the electricity system.

On the basis of these factors this chapter reviews the developments in the electricity system in order to explain them. In these explanations the focus is more on considerations, activities and interactions between actors.

5.3 The first and second energy crisis: a change of energy politics

Both energy crises, especially the first one, can be considered as change events. They are more or less coincidental circumstances that have influenced regime development. The following aspects are relevant:

- The energy crises have affected the growth model of the electricity industry of more and larger power plants. The idea of energy saving that was developed by politics from 1974 on introduced another development and change perspective in the dominant regime. The electricity industry was confronted with a broad societal and political support of the concept of fuel scarcity and the necessity to save energy.
- Energy saving has been adopted by the dominant regime mainly through the introduction of combined cycles and STEG. The combined cycle technology had several important advantages (cheap, efficient and could be integrated easily in the central station model). This technology, however, also paved the way for heat distribution and the sector was after 1974 pressured to initiated district heating projects which it did not support. The large scale district heating projects that are currently labelled as stranded costs, are a direct consequence from the first oil crisis and introduction of the need for energy saving. Moreover, the introduction of the gas turbine and combined cycles opened the path towards combined heat and power production. CHP was seen after 1974 as one of the most important routes for energy saving. The electricity industry did however not pay any attention to CHP, because it was the dominant technology for the self producers. The weight given from politics to CHP implied that the dominant regime is confronted with an alternative for central station electricity that is endorsed by society. The actors in the dominant regime, the electricity producers, have resisted the development of CHP until the middle of the nineties, see for example the discussion on remuneration tariffs, but this did not prevent CHP to develop towards a serious alternative.
- The second important consequence of both oil crises has been that the electricity industry was forced to accept active government intervention with regard to the fuel mix for electricity production. Until 1973 the central government was kept at bay. The energy crises legitimated increasing government intervention in the fuel mix of the industry. The influence of government on the sector remained, although not as direct as during the seventies. As a consequence of the fuel diversification policy the electricity production industry was forced to transform several power plants from gas to oil and coal fired power plants. Fuel diversification policies were however not very consistent as relatively shortly after the

transformation of the power plants gas became available again for electricity production. Inconsistency of fuel politics did not improve the relationship between government and the electricity industry and strengthened the belief in the electricity industry to keep government influence away.

- A third important consequence of the oil crises has been that in politics it was realised that also other alternative technologies for electricity generation need to be investigated and developed. This led to the first R&D program on wind energy, and later PV, while the mission of RCN was broadened and its name was changed in ECN.

In conclusion the energy crises affected the closedness of the dominant regime in three ways:

- The exclusive tasks of the electricity industry of security of supply and reliability is extended with a third task, namely energy saving. This task is however not exclusive to the electricity industry, but is also taken up more broadly, which is manifested in the development of heat distribution and decentral CHP applications.
- The electricity industry had to accept, under pressure of the circumstances, active government intervention with regard to the fuel mix, an area that was the exclusive domain of the electricity producers before the oil crises.
- The development of renewable energy is put on the political agenda outside of the dominant actors in the electricity regime.

5.4 The blockade of the nuclear route

- Changing societal views such as voiced in the Broad Societal Discussion show that the nuclear plans of industry and government go against the prevailing societal climate of those days. Nevertheless the plans are further developed with support of the Ministry of Economic Affairs. This is an indication for the strength (inertness) of the dominant regime.
- The changing societal climate with regard to nuclear energy (and in the general sense: increasing interference of societal groups in decision making processes previously the domain of more technocratic oriented bureacrats, politicians and industry) and the increasing societal resistance to nuclear energy further affected the autonomy of the nuclear industry and decreased the closedness of the dominant regime. The electricity industry

was more or less forced to take into account in its strategy and policy broader societal and political considerations next to security of supply and reliability.

- While the momentum for nuclear energy had already significantly dropped due to societal resistance, the risk issue and the broad societal discussion, ongoing plans were altogether stopped by the accident in Chernobyl.

5.5 CHP development

After the oil crisis CHP is in fact the only available technological alternative to save energy in electricity and heat production. For that reason political support is high for this technological alternative. The dominant regime resists the demands for decentral CHP, reflected by the need to revise the system of remuneration tariffs. Decentral CHP does not fit into the dominant model of the central station electricity system and the regime. The dominant regime disregards the steady growth of decentral CHP and realises too late the impact of CHP on central electricity production. In its production planning the electricity industry structurally underestimates the growth of CHP which consequently leads to increasing ineffectiveness of the system of central planning, one of the core mechanisms of dominant regime. Remarkable is that this corrosion of the dominant regime largely takes place due to actors that come from the inside of the dominant regime (electricity distribution companies). CHP technology has been employed in a power battle between the producers and distributors of electricity. This battle has its origins in the ownership rights of electricity companies and is brought about by the electricity act of 1989.

Therefore both technological development and changes in the institutional organisation of the electricity regime provided the building stones of the rise of decentral CHP, and have made clear that also other models of electricity production and distribution might be effective next to the central station electricity model.

5.6 The development of renewables

The energy crises initiated the first attention for renewable sources for electricity generation. R&D programs for respectively wind, PV, and biomass were started to develop these technological niches. In the seventies and eighties actors from the dominant regime were not seriously involved in these alternatives, and developments were carried by government and other actors. Under pressure from environmental problems and most importantly the climate change problem R&D efforts in renewable alternatives increased during the nineties. Now also supply push measures were increasingly accompanied by measures to stimulate demand. Moreover, distributors had committed to specific environmental goals that could be attained with increasing implementation of renewable energy. Therefore, increasingly renewable alternatives now serve as a market niche (have serious market potential). Institutional changes have been important in opening up these opportunities for renewable alternatives, and increasing climate change demands have been important in creating a market.

5.7 Explaining institutional change

It could be argued that the attack of closure of the dominant regime (the autonomy of the industry) has in fact been led by central government itself. Not technology has been the weapon to attack the sector, but the institutional organisation of the sector. After 1989 technology (CHP) and institutional reorganisation (electricity act of 1989) reinforce each other. Between 1970 and 2000 important steps were made that brought the electricity sector under control of central government and that led to important changes in the industrial organisation of electricity supply. The institutional changes of 1989 corrode the autonomy of the electricity industry to a large extent.

Moreover in the last decade two other important changes take place in the relationship between the electricity industry and government. From 1989 on the electricity industry is defined as a specific target group in environmental policy. VROM has entered the policy network of the electricity industry next to EZ. At the ministry of economic affairs a change of energy policy has taken place. The perspective of the ministry changes from security of supply to energy saving, energy-efficiency and sustainability.

5.8 Summary and conclusion

This chapter dealt with research question 3 of our research and focused on explanations for the observed development patterns on the basis of the theoretical perspective of co-evolutionary change. Figure 5.2 gives a simplified representation of the development of the electricity regime. Until 1973 the electricity regime was very stable, expanding through the mechanisms described in section 5.1. From 1973 the regime has gradually become less stable.

Although the central station electricity system is still dominant, it is now accompanied by an increasingly varied mix of other options for electricity generation.

Figure 5.2 From stability to flux in the electricity regime

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

In explaining this development we focus on development patterns on three levels and their interaction.

On the landscape level the strength of the regime has been fed by increasing electrification of the country, and has been impacted by various external events such as the oil crises and Chernobyl crisis. Increasing societal attentions for environmental problems, and increasing assertivity of society with regard to ‘technocratic’ decisions were important factors in the blockade of the nuclear route. Also in the ‘selection environment’ now environmental groups play a significant role. On the landscape level also increasing wealth in Dutch society and the increased potential of consumers to ‘allow’ the luxury of for example a PV roof, in combination with the positive environmental image, have opened up opportunities for further uptake of alternative energy carriers.

At the regime level some of the explanations for the strength of the regime have been previously formulated. Corrosion of the strength of the regime takes place through a number of factors:

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

At the niche level we have demonstrated the importance of the development of the gas turbine by actors outside the regime and partly also the technological domain. Most renewable energy technologies have been developed because of their expected potential. Societal groups, specific R&D institutions and government have played an important role in this development. Currently several niches are in development that also have potential on the market, and several actors are trying to develop this potential. Some of the niches have potential to develop towards hybrid forms with existing technologies, such as biomass with co-combustion and gasification. Other technologies have potential to develop because of the institutional changes and technological changes that may open up the potential for much more decentralised and small-scale units of electricity generation.

6. Governance and Sociotechnical Change in Electricity Generation and Use

6.1 Introduction

This chapter focuses on the role of governance in sociotechnical development in electricity generation and use and will offer suggestions for the modulation of dynamics in the interaction between the electricity regime, the sociotechnical landscape and patterns of niche development. Our analysis has shown that multi-level and multi-actor processes establish the course of sociotechnical change. These processes do not solely have an ad hoc character due to contingencies but are to some extent pre-determined by accumulation of competencies and path dependencies that form the essence of the electricity regime. Interaction of actors, their strategies and actions are moulded by arrangements embedded in the course of sociotechnical development. We use the term governance to refer to the way these interactions are structured, controlled and/or co-ordinated in various 'conditions of ordered rule' (Rhodes, 1996) or so-called modes of governance. It is important to note that 'governance' is not similar to government but reflects the way interactions occur between actors and their strategies, such as the strategies of the various actors in the electricity system, including government. We will therefore analyse the various strategies of actors to influence technological development in the electricity domain, and the role of government policy with respect to this, thus effectively answering research question four of this subproject.

The key assumption is that the success or failure of diffusion and implementation of new technology is to a large extent dependent on the co-ordination between the actors involved. It is the interaction of such actor strategies in different networks that play a prominent role in the success or failure of the introduction of new technologies and the technical transformations as a result of this. In this chapter we focus on the role of modes on governance in configuring these interactions. For example, modes of governance based on competition lead to different configurations of interactions and strategies of actors then when based on monopolistic organisation. This has also relevance for government policy because the effective application of specific incentives or instruments is dependent on how well it fits the mode of governance. Modes of governance are related to sociotechnical change because the dynamics and interaction of various actor strategies shape the direction and patterns of sociotechnical change. But vice versa also the patterns of these interactions are grounded in the strategic games, markets and institutions that are part of the electricity regime. Thus the mode of governance emerging for electricity generation and use at the beginning of the 20th century ran parallel with the rise of the central station power system. In the next paragraph we give a more detailed analysis on the structure of governance in the period under research.

Changes in the mode of governance, conditioned by and part of sociotechnical change, can open new areas and opportunities (e.g. for governments) to govern (groups of) actors and thus affect the conditions under which actors are more likely to develop and implement more climate friendly technologies. We will illustrate in section 6.3 how change in the mode of governance in the electricity regime has led to changes in actor positions and their strategies. Section 6.4 in this chapter focuses on the role and influence of government policies in the process of sociotechnical change, allowing for a twofold analysis of improving governance conditions. Firstly, a focus on the 'match' of the government tools (instruments) and governmental approach (policy styles) with the prevailing mode of governance, and secondly the 'fit' of the government tools and governmental approach to the dynamics of sociotechnical change. In the final section we sketch various technological paths in response to the climate challenge that are either visible, or apparent in the mindset of relevant actors. This allows us to analyse the fit of current government strategies to the various paths and to discuss strategies for modulation of sociotechnical change into a climate friendly direction.

6.2 Structure: from monopolistic organisation to a pluralist mode of governance in the electricity regime

This paragraph focuses on the structure of governance in electricity generation and use. We discern three periods with distinct governance structures, in a following paragraph we will focus on patterns of sociotechnical change that have induced these changes in governance structures. The first section focuses on the period until 1989, with the electricity act of 1989 initiating the separation of distribution and generation. The second on the period 1989-1998, with the electricity act of 1998 marking the development towards a liberalised electricity market, and finally the period after 1998 is analysed. In a subsequent section we will describe major changes in terms of position and strategies of the core actors related to the changes in governance.

6.2.1 Period until 1989: monopolistic organisation

Monopolistic organisation of electricity generation and distribution has long dominated the electricity system. It emerged in the beginning of the twentieth century, and was an excellent match to the development of the central station electricity model, especially when the dominant guiding principles of the system were availability and reliability and the heuristics of design were based on the relation between increasing efficiency and increasing scales of the thermal, steam turbine based, power plants. Governance in the electricity system was dominated by government actors and the electricity companies. Until 1989, public owned vertically integrated electricity generation and distribution companies were organised in small scale geographical monopolies, with clearly defined positions and legally authorised tasks reflecting the public utility character of electricity supply and the company's public service obligations. These companies were autonomous in producing and distributing for the region they served, and were internally organised as a network, with the SEP as its main coordinator. Authority of the national government was more or less limited to areas such as the fuel base of the electricity companies and to standards for the functioning of the power plants.[98] The electricity sector operated as a closed front against a national government that was developing central control over electricity supply, especially after the two oil crises that reinforced the need for increased efficiency and energy saving.

This mode of governance, which can be characterised as centralist and closed (see also previous chapter), strongly affected a number of technological developments that were initiated because of concerns regarding security and reliability of supply, efficiency and the environment. It explains to a large extent the failure of initiatives for the introduction of nuclear energy, wind energy, and heat distribution, because it was unable to anticipate the multi-actor and multi-level processes underlying these technological changes. 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. At the landscape level, changes such as the

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[98] The responsible provincial and municipal shareholders authorised the investments and electricity tariffs. National standards were in place regarding efficiency of power plants and emissions of for example NO_x and SO_2, but not for CO_2. The Ministry of Economic Affairs had to approve the bi-annual capacity plans of the sector (Maar, 1987).

increasing role of civil society and increasing environmental concerns became major obstructions for the further implementation of nuclear energy and were not anticipated sufficiently by the actors in the regime, e.g. government and the electricity sector. Thus, the de facto mode of governance, which had developed in the electricity regime over a period of decades and had its legitimatization in securing electricity supply in convergence with economic growth, was increasingly being challenged by other factors (environmental and risk concerns) and actors (from civil society). Apart from being unable to legitimize choice for nuclear technology the de facto 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 regime, e.g. with 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.

The experiences with nuclear energy and wind energy suggest that government R&D strategies have long breathed the belief that the course of technological development and diffusion for these technologies is malleable. Retrospectively, however, what stands out is that the chosen path of technological development was not very well embedded in society, for example because of lack of involvement of institutions that play a role in adapting the technological configuration in society and of users of electricity. It has foremost been a technical top-down effort (technology-push), largely isolated from societal influences. It has been technical in the sense that the emphasis on the artefacts was dominant (technical design, technical standards, etc.), because engineers and technicians were dominating decision making, but it has also been technical in the sense of the decision making process surrounding processes of choice for R&D and implementation of projects. In our explanation these failure factors are related to the dominant guiding principles of the electricity regime such as large scale, central planning, etc. and its governance arrangement in which the electricity sector and government were mainly concerned with security of supply and the technical, large scale way to handle this issue.

Moreover, we also see that in this period an organisation for energy R&D was build up in the Netherlands which was very much centralised, both in terms of structures for funding and in terms of research institutes. This also contributed to technological development of alternative paths in which technology has often been developed without participation of users and related groups. In the case of the development of wind energy, for example, the technological development has been virtually independent of relevant actors such as municipalities, local users and environmental groups.

The examples of wind energy and heat distribution also point at the importance of meso-level of competencies and beliefs of actors and path dependencies related to accumulated infrastructures. Competencies and beliefs from actors in electricity sector related to an infrastructure of large-scale power plants and electricity distribution to customers. The electricity sector only became involved in large scale heat distribution and wind energy development because they were pressured by government and as a protection of their core-business, while their competencies, networks and supply orientation did not fit development of heat distribution and wind energy. Later, when the distribution companies formed coalitions with actors outside the electricity regime and became more small scale and market orientated, they proved to be much more apt to develop heat distribution and wind energy.

Historically, the development of monopolistic organisation with government and the electricity supply industry as dominant actors worked well when the guiding principles of the electricity regime were still valid. This setting, however, also led to struggles between the national government and the electricity sector, for example regarding the implementation of nuclear energy and the efficiency of the Dutch system. Although the national government initiated the development of various technological options, such as nuclear energy and wind energy, in the end it was the electricity sector that decided on the terms under which the technological option was implemented (nuclear energy) or not implemented (wind energy). However, the national government considered efficiency far from optimal due to the fragmented nature of the electricity sector, with numerous small production and distribution companies. The efficiency debate between the national government and the electricity industry stretched a period of thirty years, in which research was conducted, various committees released advice, strategic games were played, adjustments in the organisation of the electricity sector occurred, and in which eventually compromises were settled. Only in 1989 this political process was concluded with the introduction of the first national act for the electricity sector, the Electricity Act of 1989. In this setting the role of other actors in governance of electricity generation and use was limited, although the role of industrial actors became more important towards the end of this period, signifying the potential of efficiency improvement through implementation of cogeneration. Anticipating the new electricity law of 1989, the national electricity system changed. Generation and distribution, which were integrated before

1985, became vertically disintegrated in electricity generation and distribution companies, and due to mergers the number of generation companies reduced from 14 to 4. The four power generators intensified joint cooperation by technical and economic dispatch and mergers reduced the number of distribution companies (Arentsen et al, 1997). The end of this period marks a turning point in governance structure created by the unbundling of production and distribution companies.

6.2.2 Period 1989-1998: separation of distribution and generation

The Electricity Act of 1989 changes the nature of the governance arrangement. After 1989, due to imposed vertical disintegration, a more pluralist arrangement is developing due to increasing competition between electricity producers and distributors. The 1989 electricity law legally authorized the new structure of the electricity system and reinforced the public dominance of the system, although public shareholders were set at distance to the management of the companies. The national government, however, established final control over the electricity system, by means of control of new entrance of electricity generation and distribution, the authorization of investments and electricity forecasts of the companies, tariff control and approval of electricity import and export. The electricity act 1989 also offered legalized opportunities for decentral power generation next to the centrally coordinated power generation of the four generation companies cooperating under SEP. These legal opportunities were meant to increase the efficiency of the electricity system but initiated a boom in CHP-based generation technology, which led to surplus capacity in national electricity system and initiated the end of the central planned system of electricity production under SEP. The previous stable actor configuration started to change because distributors developed a strategy to compete with electricity generators, and engaged in coalitions with various actors from industry. One of the effects was that heat distribution, which had been unsuccessfully implemented by the central producers, was effectively carried out by new coalitions of industries and distribution companies, also because of an accompanying policy package of stimulating measures.

The change of governance structure regarding the system of electricity generation and distribution is accompanied by a changing mode of governance regarding environmental issues that confront the electricity regime. Whereas previously environmental standards were imposed, the target group policy introduced in the first National Environmental Policy Plan led to more consensual styles of policy making. Command and control strategies are being complemented by various voluntary agreements between government and industry, such as agreements on energy efficiency and emissions of NO_x, SO_2, and CO_2. In 1990 electricity production companies concluded a voluntary agreement on reduction of SO_2 and NO_x (acidification covenant), however discussions between producers and government on a CO_2 covenant were terminated in the middle of the nineties. In 1991 electricity distribution companies concluded a voluntary agreement with the national government to reduce CO_2 emissions with 9 million tonnes, in 1994, with the publication of the second NEPP, this target was doubled to 17 million tonnes of CO_2 for 2000 relative to 1990. With the funds generated by the MAP-levy, the distributors also became more intensively involved in wind energy as an option to generate electricity by themselves, and to reduce CO_2 emissions. Two components of changing governance structures, increasing competition and internalising environmental goals therefore were beneficial to the development of alternative electricity generation options, and especially wind energy in the beginning of the nineties. The governance structure was however still predominantly of a central character, with national goals for renewable energy, and the voluntary agreements were concluded with limited actors, national government and the energy distribution sector. While the sense of urgency regarding the climate change problem sharply increased in this period at the national governmental level, this diverged from the developments at the local level. Commitment to the ambitious national goals for renewable energy and CO_2 reduction was low because national targets have not been translated to the local level. Research has shown that municipalities seldom have concrete reduction targets for greenhouse gases (Menkveld et al, 2000b). The implementation of wind energy has been frustrated because permits were often not granted because of problems of spatial integration. This is one of the reasons the target of 1000 MW wind energy by 2000 was not realised. The development of locations is in practice time consuming, requires complex procedures, and often meets significant resistance at the municipal level (Menkveld et al 2000a).

Intensification of environmental policy at the end of the eighties, the introduction of target group policies, and first goals for CO_2 reduction, also induced crossovers between various policy fields. Thus, in waste policy an increase in electricity generation through waste incineration became a specific objective both to realise policy goals to reduce CO_2 emissions and to reduce waste dumping. Technology programs were initiated to explore the potential of electricity generation with waste and biomass. Related to agricultural policy also explorations regarding the potential of manure as a source for electricity generation (mainly through fermentation) were initiated. Initiatives from other policy areas initiated a discussion regarding various environmental issues related to electricity generation based on waste or biomass,[99] thus reflecting an increase in the number of actors involved in electricity generation and the complexity of governance in the electricity system.

6.2.3 Period after 1998: towards a pluralist mode of governance

From 1998 on the electricity market liberalises from monopoly to a market based system. The Electricity Act of 1998 legally formalises competition in electricity generation, trade and supply. Transport and distribution stays under monopoly control but access to networks is open for all. The introduction of the market-based model marks the end of co-ordination and planning of electricity supply by the SEP. Electricity generation companies develop from public owned companies to private companies, with the a take-over of three of the four production companies by foreign companies. Distribution companies developed towards larger scale, with three large multi-utility companies dominating the market. Moreover, various consumer groups phase-wise develop from ‘captive’ consumers to ‘free’ consumers, with households set to have free choice of electricity in 2004. Now a variety of actors are positioning themselves to provide electricity services to the various customers when they will have free choice. In terms of governance a pluralist arrangement has emerged with competition between a variety of actors, but also with several new actors entering the electricity system (such as electricity traders and foreign actors). The position of government has shifted to regulator of the market. The playing field for governance is steadily moving towards the European level, with Dutch government complying with European law regarding liberalisation and competition. In section 6.3 we will more specifically focus on the strategies, outlook and expectations of actors within this pluralist mode of governance.

6.3 Evolution: changes in governance and the electricity regime

6.3.1 General patterns

Our analysis has shown that the impact of changes in the mode of governance has been pervasive on the strategies of various actors. First of all, the network mode of governance internal to the electricity companies and with related interests co-ordinated by the SEP has been replaced by a pluralist model in which individual pursuit of interests is the dominant

[99] Such as discussions whether input can be classified as waste or raw material, which has implications for permitting procedures for installations and transport. Also discussions regarding emission standards for waste incinerators compared to power plants is an issue.

orientation. While in the network mode long term perspectives such as more fundamental R&D activities were carried collectively by SEP and KEMA and stimulated by national authorities, in the pluralist mode of governance actors are much more inclined to pursuit of short term self-interest. Important to note is that these developments, while having huge impact on (environmental) strategies of actors, were not induced by 'sustainability' considerations but by ideological considerations regarding expected differences of efficiency and optimal allocation of systems driven by either the state or the market. Other factors that facilitated the changes in governance structure were the technological stasis steam turbine technology and the emergence of more flexible gas turbine technology that reduced the rationale for large-scale generating units, and increasing demands from industrial actors and societal actors, such as laid down in the broad societal discussion. The international trend towards market orientation and successful examples of liberalisation in other countries also played a role (see also Hirsh, 1999).

Moreover, developments in governance also have implications for the electricity regime. The mode of governance based on autonomy and a natural monopoly for the electricity companies which existed until 1989 matched very well to the dominant design of the electricity regime: the central station electricity system. The change of mode of governance from 1989 on creates pressure on the guiding principles of the central station electricity system. Various actors grasp opportunities to generate electricity efficiently on a decentral level, also facilitated by the development of STEG technology. The process of liberalisation from 1998 on gives further opportunities for an increase of the diversity of actors within the electricity system. Moreover the international dimension becomes more and more important, among others because liberalisation of the energy market has brought import of electricity within the reach of the free electricity consumers.

The main question is what these changes signify for the role of sustainability within electricity generation and use. We think that in the various periods the following patterns are visible. Before 1989 issues of sustainability were managed by imposing external constraints and demands to the electricity regime. Demands for sustainability were dealt with within the existing technological configuration, by a number of modifications (often end-of-pipe) leading to emission reduction of various substances. The mode of governance acted as a barrier for other actors outside the electricity sector to give shape to the demands of sustainability because of the difficulty of producing electricity outside the established electricity companies. After 1989 especially the distributing companies profile themselves as 'agents of change', and they use ‘sustainability’ in order to distinguish themselves from, and to compete with, production companies. Initially competition with the central producers occurs through the development of decentral cogeneration in collaboration with industry and other sectors. Later green electricity is viewed as a potential market segment. Both developments were also induced by their commitment to increased efficiency and reduction goals for CO_2, and the opportunity to partly finance this through the MAP levy. After 1998 a divers group of actors is involved in the production and distribution of electricity and are expected to provide various electricity services to attract various customers.

6.3.2 Liberalisation, climate change and the influence on actor configurations

In this section we will explore the development of the strategies of the main actors involved in electricity generation and consumption. We mainly view two major developments that strongly influence strategies of these actors, the process of liberalisation and privatisation, and climate change concerns. The dominant focus will be on recent strategies from the various actors and the ways in which they cope with these two main developments.

Producers

In the development towards a liberalised, European market the four Dutch electricity producers[100] have been mainly concerned with safeguarding their market share in a market still characterised by surplus capacity. Production companies feel confronted with a high level of insecurity, both in terms of the development of the electricity sector in terms of supply and demand, government policies, and the long-term development of the electricity system. Their focus is mainly on securing market shares by improving cost-effectiveness and reducing prices through processes of re-organisation. R&D strategies of electricity producers also have less of a long-term perspective, also because collective financed R&D under co-ordination by the SEP has ended. R&D capacities are now more shaped towards the ability to anticipate on technological changes and breakthroughs by other actors. The period for planning and setting goals has been reduced. As electricity production becomes a competitive business, general business standards for payback times have to be used. Long term planning now covers five to ten years, instead of up to twenty years previously.

[100] Here we mean the electricity producers with power plants in the Netherlands. In 2000 three of the four previously Dutch producers are foreign owned.

Although electricity producers state that they will take environmental interests seriously, their main concern is competitiveness. Because competition has become more international, the producers also increasingly adopt international strategies. For example Electrabel (which has taken over EPON and its Dutch power plants), has closed down its gas-fired power plant in the East of the Netherlands and has recently opened a coal-fired power plant in Belgium because coal prices have remained at a relatively low level whereas gas prices have increased in 2000 and 2001. On the other hand, EPON, the Dutch affiliate of Electrabel, is keen to help generate growth in the use of renewable energy in Europe. According to EPON, two renewable energy options are promising for large-scale production: energy from biomass and wind energy. (Website EPON, 2001). Currently, producers with coal-fired power plants in the Netherlands are experimenting with co-combustion of biomass, also aimed to comply with future emission standards for CO_2 for power plants in which CO_2 emission standards are based on the performance of natural gas fired power plants.[101] Strategies of the large electricity producers are focussed on proven and cost-effective technologies because their strategy is to provide electricity for mass consumption embedded in the central station electricity model. International competition between electricity producers extends the central station electricity model from the national to the European level. In this setting import and export of electricity, through the electricity grid, becomes an important issue for the more efficient allocation of electricity production units.

Distributors

From 1989 on distribution companies have become more actively involved in electricity generation as a competitive strategy vis a vis production companies, mainly in CHP projects in co-operation with industry. While the beginning of the nineties proved to be a fruitful period for installation of CHP due to a combination of policy measures, landscape developments (electricity and gas prices), and fiscal measures, investments of CHP have slowed down in recent years due to lower electricity prices and higher gas prices (Energieconsulent, december 2000). The new position of distributors also induced a strategy towards the broadening of their activities (product diversification), in order to bind new customers. New activities involved cable activities, waste management and telecommunications. All distributors are now developing towards multi-utility companies, in order to be able to present a full package of

[101] Currently, these standards are expected to be in force by 2008. EPON is now replacing 5 % of its coal by biomass in its Gelderland power plant, and aims to increase this percentage to 15 %. EPON also investigates the construction of an installation for biomass gasification located at the Eems power plant (Website EPON, 2001).

services to purchasers that is more efficient and cheaper than the individual services. The concentration in energy distribution continued and at this moment three giant energy companies dominate the Dutch market. Two of the three of them have adopted in one way or another to the multi-utility concept of organisation, offering all kinds of energy products (electricity, gas, heat and cold) as well as other types of utilities, such as water, telecom and waste treatment.

Changes in institutional organisation, the process of liberalisation and increasing competition in the electricity sector have driven strategic and cultural change in energy distributors. In anticipation of liberalisation they have become much more customer oriented and focused on its product and marketing. The market was less of a driving force when the electricity sector was still characterised by monopolistic organisation and stability. The companies' culture changed also because more economists came to occupy key positions, whereas previously management was dominated by engineering backgrounds. The increasing market orientation of energy distributors explains why the concept of green electricity could emerge and also why, despite resistance in the company, it was backed by top management (Hofman, 2001).

Government supported this development by the exemption of green electricity from the regulatory energy tax. Green electricity should be considered product diversification and a business opportunity and congruent with the general strategy of the distributors. One strategy has been to stress distinctive features of the green product, showing in different names (and origins[102]) and prices for green electricity. An important aspect of green electricity is also the coalition that has been formed between energy distributors and other actors to increase legitimacy of the concept and to have external verification of origins of green electricity. At the start of green electricity, in 1995, the Dutch branch of the World Wide Fund for Nature was the first NGO to become active through its association with Dutch energy distributor PNEM.[103] Later also Greenpeace became active in the promotion of green electricity. Until 2000 distribution of green electricity takes place to 'captive consumer' but the market for green electricity will become free in July 2001. Although competition between the different distribution companies was not in effect until July 2001, they have anticipated on the liberalisation of this niche market. Demand for green electricity is one of reason for the distributors to search actively for ways to produce or buy renewable energy.

[102] Nuon for example does not produce green electricity with biomass, Essent and Eneco do.
[103] PNEM later became part of Essent.

In the last decade the distributors have been active in energy conservation, for example through implementation of the MAP. The environmental action plan however has come to an end in 2000 but some the funds are still available for energy saving activities of the energy distributors. From 2000 on energy saving activities of energy distribution companies are therefore being led by demands of the market. Thus, one of the strategies of distribution companies is to provide full service to customers, including energy conservation.

Government actors

- *European Union*

The European Union is playing an increasingly important role in recent years for the development of energy policies. It has influence national policies by providing new goals and instruments or a level playing field for industries (liberalisation, such as through the EU electricity directive, Joint Implementation and subsidy schemes like SAVE and Joule-Thermie, European standards for energy efficiency and efficiency labelling). It has also sometimes blocked implementation of specific (inter)national policies. Examples are the equivalent treatment of kerosene as other fossil fuels; a low (6%) VAT tariff on green (renewable based) electricity as suggested in the Renewable Energy Action Program (Ministry of Economic Affairs, 1997); and the international levy on energy for which a decision is postponed due to rejection of a number of member states although the European Commission was in favour.

- *Ministry of Economic Affairs*

The Ministry of Economic Affairs has responsibility for energy conservation and the promotion of renewable energy. During the last decade the tasks and budget for these activities have increased considerably. The Ministry of Economic Affairs is furthermore the most important public advocate of cost minimisation (and therefore liberalisation) and protection of industry interests (international competitiveness). In its strategy for electricity supply it has therefore often tried to combine the various goals from the various subdepartments. Thus, both development of nuclear energy and wind energy has been promoted to solve problems with regard to energy supply and to develop a national industry. Also the mix of objectives has induced a strategy in which policy measures are chosen that have a minimum risk of threatening international competitiveness of industry. Market conform measures are generally favoured. Currently, the possibilities of emission trading are explored, but it is uncertain whether and when they will be used. However, it is generally assumed that the electricity sector would be among the most suitable sectors for emission trade.

With regard to renewable energy the Ministry of Economic Affairs beliefs that biomass and wind energy are the most attractive options in the short term because wind energy can be competitive and has significant potential if permitting procedures are accelerated, proof regarding conflict with zoning schemes is reversed, and municipalities more actively look for and appoint locations. Supply of biomass can grow sixfold if heat production with biomass is validated better, emission standards for biomass power plants are more lenient, and the image of waste as an energy source is improved (Ministry of Economic Affairs, 1999a). In terms of policy instruments the regulatory energy tax is setting the tendency towards greening of the tax system. Moreover a system of trade in certificates for renewable energy is considered.

- *Ministry of VROM*

The Ministry of the Environment holds responsibility for the effects of energy use on the environment and aims therefore at reduction of emissions and especially CO_2. VROM is carrying out Dutch climate policy and is thus responsible for international negotiations regarding the reduction of greenhouse gases. VROM is actively involved in the implementation of the Kyoto targets to which the Netherlands is committed (although not ratified yet). VROM also is actively involved in the discussion on waste policy and the use of biomass and waste for electricity generation.

- *Provinces*

Historically, provinces have played an important role in the development of the electricity system as public owners of electricity companies. However, the role of provinces in energy policies has been much more limited. Their only formal tasks are in wind energy and granting environmental permits. Because of the voluntary agreements on energy efficiency the efforts for the latter task were not substantial. It is expected the provincial efforts will increase because of the introduction of the benchmark agreement in which large industries are party, for which provinces are the permitting body.[104] For the case of wind energy only two of the seven provinces involved managed to reach the goal set in 1991. As a new agreement for wind energy is about to be entered, provinces have to become more active.

- *Municipalities*

The ambitious targets with regard to renewable energy, such as 1000 MW for wind energy in 2000 as agreed in 1985, has generally not been translated to the municipal level. Municipalities have only become active in implementation of renewable energy by their own choice. Municipalities however hold an important position in the implementation of various renewable energy projects because of their authority in granting permits for location of energy installations, and because they are responsible for the decision making procedures regarding zoning schemes. However, studies on the attitude of local citizens regarding wind energy consistently show that a majority is favouring wind energy (Novem, 2000). Currently only a limited number of municipalities have an active policy regarding wind energy (Menkveld et al, 2000a), although some municipalities have been active and successful in implementing wind energy. Also with regard to climate goals, targets at the national level have not been translated to the municipal level. Municipalities have played a role in increasing energy efficiency because of their authority in integrating energy into environmental permits. Moreover, with the electricity act of 1998 municipalities have the legal opportunity to decide on the local energy infrastructure. Several municipalities have been active in collaboration with for example distribution companies to implement renewable energy projects. For example, the municipality of Amersfoort has facilitated the development of a new housing district, Nieuwland, with 1 MW of PV capacity, the largest in the world in 1999. “The local authority in Amersfoort drew up the plan of Nieuwland in the summer of 1992. The council wanted a residential area that could offer more, they were looking for quality and sustainability” (Bouwmeester and van Ijken, 1999: 30). This resulted in a plan from the distribution company REMU with the use of 1 MW of solar panels. This example shows that municipalities can have a significant impact on the energy infrastructure in housing districts. The process of liberalisation both offers opportunities and threats for the role of municipalities in the implementation of less carbon intensive energy infrastructures.

Industrial actors

The main strategy of industry through the years has been prevention of the introduction of costly measures for energy conservation because this threatens international competitiveness. The industrial energy interests always have been well organised in the Netherlands. Significant parts of Dutch industry are energy intensive and therefore energy costs have been and

[104] IPO, *Interprovinciale rapportage milieu, water en natuur 2000*, IPO publicatienummer 135, Den Haag, 2000

still are major themes of interest. Until 1998, industrial energy interests were organised in two separate organisations, the Vereniging Krachtwerktuigen, representing the energy interests of smaller industry and Sige, representing the energy interests of large industries. In the course of the eighties both organisations were active in improving remuneration tariffs for electricity produced by industry in order to facilitate cogeneration. The deteriorating conditions for co-generation after 2000 has led industry to ask for compensation for non profitable cogeneration units. It is estimated that in the beginning of 2001 around 20% of cogeneration capacity is not utilised due to low electricity prices and relatively high gas prices.

Power equipment producers

The electrical equipment sector (both devices for electricity generation and consumption) is composed primarily of large multinational firms selling world-wide. Restructuring, competition and regulatory reform is breaking down traditional boundaries between electricity, fuel, and equipment suppliers. There is a growing number of mergers and joint ventures involving electricity utilities, gas utilities, gas pipelines and gas marketers (Joskow, 1998: 51). Internationally, the bulk of the R&D activity and funding affecting equipment used to supply electricity is undertaken by the manufacturers of electric supply equipment and not by electricity suppliers (Joskow, 1998: 49). Competition is likely to further depress utility R&D expenditures focused on generation technologies (Joskow, 1998: 49). Competitive forces are likely to stimulate research, development and innovation among manufacturers of equipment used to supply and utilise electricity. This is also where the important innovations in CCGT technology came from, drawing on complementary research on the development of efficient jet engines for commercial aircraft. Competition is creating new market opportunities for innovations in generating technology aimed at improving thermal efficiency, reducing the minimum scale of generating units, improving reliability, and reducing the fraction of value added related to on-site rather than factory construction. Large equipment producers are focussing on flexible, relatively small scale generation units that they believe can become the core of the emerging system of distributed utilities. In this system, distributed power plants can supply industrial facilities, shopping centers, hospitals, office parks, airports or entire sections of cities (Eberl, 2000), while electricity is produced by connecting a variety of small scale decentral power units, which can be composed of fuel cells, small scale gas turbines, wind power units etc. According to Siemens, small scale hybrid systems of fuel cells with micro gas turbines can be expected to reach efficiencies of close to 70%, with first commercial applications expected by 2002. The compact size, reliable and remote operation, and environmental soundness of fuel cell power plants means they can be located very close to the user, among others eliminating the need for long and costly power lines (Eberl, 2000). Competition is also creating demand for new metering equipment that can measure real time energy consumption and signal price changes to consumers as well as appliances and equipment that can respond quickly to this price information. The increased demand for all of these types of equipment is likely to stimulate private sector investment in R&D by potential equipment manufacturers (Joskow, 1998: 49-50).

Large energy companies and power equipment producers are involved in various technological development paths for electricity generation. Siemens, for example, is involved in developing small scale gas turbines, fuel cells, and PV technology. Also Shell is involved in PV technology and the development of fuel cells and expects hydrogen to be one of the fuels of tomorrow (Romm, 1999). They expect these technologies to become a significant part of the electricity system in the future.

Foreign producers of electricity

Liberalisation, as an effect of the Electricity Act of 1998, introduces new actors in production as well as in distribution. Although imports have existed through the years, and foreign producers always played a role in the Dutch electricity system, imports have risen steeply with liberalisation of the electricity market in 1998. For example, large consumers now have the ability to buy electricity from abroad, and some have started doing this. The position of foreign producers has therefore become more significant in the Dutch electricity system. As electricity prices abroad are generally lower[105] the interest to import electricity is large. The demand for import of electricity is exceeding the transmission capacity for imports and has to be divided among the interested actors. All in all imports have increased over the years and since 1999 its growth has been caused through imports of non-captive customers and distribution companies. For the division of the import capacity[106] the high voltage grid administrator, TenneT, uses an auction[107] but also takes into account historical claims.[108] Due

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105 According to all consumers interest groups 2,25 ct / kWh (Energieconsulent, nr. 10, 2000).
106 The total maximal transport capacity for the five connections abroad amounts to 3900 MW (TenneT, website, 2000).
107 In fact several auctions, for annual imports (900 MW), monthly imports (550 MW) and daily imports (at least 100 MW).
108 Contracts of SEP with foreign organisations with a total capacity of 1950 MW.

to increasing imports, surplus electricity generation capacity by central producers has increased.[109] As a result, central producers are unlikely to invest in new large scale power plants.

Consumers

The position of consumers is expected to change drastically in a fully liberalised electricity market. Previous captive consumers will have a free choice of electricity. The first steps have been set in the Netherlands with the large industrial users having free choice of electricity provider. The change signifies that in the chain from electricity generation to consumption, and production decision powers could potentially shift towards the consumer. This is also expected because there will be a supply of new products and services regarding electricity. Companies will search for ways how to attach consumers. Green electricity and its marketing is one example of this. Marketing will become much more important, and distribution companies are already engaged in advertising campaigns. Apart from having an effect on providers of electricity, consumers themselves will also be affected by the changes. The consumer will start to think about the electricity product and service it requires. While most households may not even consider changing the contract it will automatically receive when the electricity market becomes free, some 'leading edge' consumers may consider the various alternatives of electricity provision. These consumers are the ones that will be targeted by providers that offer new kinds of electricity services and contracts. Other possible developments include the formation of consumer groups that have more bargaining power opposite electricity providers. Also new actors like energy brokers will play a role as link in the chain in electricity generation and use.

6.4 The role of government policy in sociotechnical development

While the previous sections focussed mainly on the relation between governance and the position of actors in the electricity regime, this section focuses more specifically on government policies, such as the development of goals, policy instruments and strategies, expectations and ideographs, their influence on niche development and their interaction with prevalent modes of governance.

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[109] As another effect of the high imports the national CO_2-emissions, which are attributed to the country of origin for the electricity produced, decreased in 1999 compared to 1998.

6.4.1 Energy policy: from diversification to energy saving to climate policy

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

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

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

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

From the middle of the nineties on climate change concerns have increased due to two developments. Firstly, evidence regarding the impact of human induced CO_2 emissions on the climate has become more strong and is now accepted in most of the academic and government circles. Secondly, it has become clear that the Netherlands is well above the interim targets set to reach the Kyoto goals for 2010. The Dutch Minister of the Environment has expressed the importance of reaching this target, also to legitimise international agreements and the Dutch frontrunner role in them (Pronk, 2001). Although at the Ministry of Economic Affairs it is expected that through effective implementation of current policy instruments these goals will be met, unofficially there is agreement that more intensive and different strategies need to be implemented. Now, more and more actors in government and other circles express their belief that the electricity system has to change in a more fundamental way. One of the first actors to express this was the General Energy Council (AER), the main advisory body on energy issues for the Ministry of Economic Affairs. In its 1999 advice it proposed the introduction of a compulsory share of renewable sources in electricity production (AER, 1999). An important element that is also stressed by the AER is the fact that in the previous governance arrangement, with a limited number of actors, it was relatively easy to conclude agreements, but that in the current situation with more actors new policy instruments are necessary to promote the transition towards a sustainable electricity system (AER 1999). Also the advisory body for the Ministry of VROM stresses the importance of a transition towards a carbon poor energy system in its advice of 1998 and expresses its concern regarding the results of Dutch climate policy (VROM-Raad, 1998). It also acknowledges that the possibility of CO_2 storage and decarbonisation of fossil fuels needs to be considered, also because it fits the changeover to a hydrogen economy and the use of clean and energy efficient fuel cells (VROM-Raad, 1998: 9). In terms of new policy instruments it introduces the possibility of emission trading regarding CO_2. More recently the Social-Economic Council (SER) expressed the need for a so-called Deltaplan for a sustainable electricity system. Among others this was inspired by the doubt regarding the feasibility of current policy targets (SER, 2000: 3). One of the elements the SER stressed was the absence a central institution that can integrate various objectives from different parties, especially in the era of liberalisation.

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

6.4.2 Energy oriented technology policy

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

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

Another observation is that R&D strategies have a dominant national focus while technological development for electricity generation and use is foremost an international affair. In some cases this can lead to a divergence between national R&D strategies and technological opportunities developing outside the Netherlands. One example is the emergence of the gas turbine and STEG, which to some extent was slowed down due to a switchover to coal fired power plants at the end of the seventies and beginning of the eighties, both promoted by a diversification policy and specific clean coal R&D program. Internationally, R&D of large power equipment producers was very focussed on the development combined cycle gas turbines, a clear indication for the high expectations that these actors had regarding this technology. An important element of R&D policies is therefore to keep track of technological trajectories that are developing for electricity generation and use throughout the world. Clearly, it can be anticipated that the R&D activities of major players like Siemens-Westinghouse and Shell in the field of fuel cells, micro turbines and PV technology, will have a more pervasive impact on electricity generation technologies than energy R&D activities in the Netherlands.

6.5 Evaluation and modulation of paths towards a carbon free electricity system

This section explores how technological paths can become embedded in a transition towards a less carbon intensive electricity system. A transition is defined as a set of related changes in several areas: technology, structure, institutions, behaviour, culture and intentions.[110] Current paths of technological development are very much rooted in the fossil based system. Nevertheless, we also witness the development of several niches, both technological and market, that provide an alternative to fossil based electricity generation. Further development and penetration of these niches can provide a solution to the main problem of the current electricity regime, emissions of CO_2 and the related climate change. The main challenge here is to develop paths in which the development of niches initiates a transformation of the current regime based on fossil fuels. In a first paragraph we derive some lessons from past government policies. In a following paragraph we indicate main directions developments in the electricity system can take along two important dimensions in the electricity system. In a final paragraph we give suggestions for modulation of patterns of sociotechnical change in the electricity domain.

6.5.1 Lessons from government policy

In section 6.4 we have provided an overview on government policies focussed on the electricity system. In this paragraph we derive lessons from the success and failure of these policies. Relatively unsuccessful examples of government policy are the development of nuclear energy and wind energy. Relative successful examples are the development of CHP and green electricity. In our view the explanation for success and failure is rooted in patterns of sociotechnical change and modes of governance visible in the electricity regime in the respective periods. Two main conclusions are:

- *When policy incentives and goals do not run parallel with modes of governance and (specific) actor strategies the chances for success of policy intervention is low.*

The experiences with nuclear energy and wind energy in the seventies and eighties provide the background for this and have been analysed in more detail in section 6.2.1 and earlier chapters.

[110] Definition taken from te Riele et al, 2000.

- *When policy incentives, goals and alignment strategies are well timed, and connect to modes of governance and actor strategies, momentum can emerge especially in combination with supportive (landscape) factors.*

The experiences with decentral CHP from 1989 on and with green electricity in the end of the nineties provide examples of successful strategies. In the case of decentral CHP price development of electricity and gas also facilitated this, just as in the beginning of 2000 reverse price developments have deteriorated the outlook for decentral CHP. The emergence of green electricity can be explained from changed actor strategies due a change in the mode of governance. While previous efforts in renewable energy were dominantly policy-driven, they became increasingly market-driven with the success of green electricity. A coalition of diverse actors has proven to be very effective in spreading the concept throughout the electricity system. Also policy has played a very significant role in this process by introducing the regulatory energy tax and exempting green electricity for this tax, which effectively led to a competitive price for green electricity compared to conventional electricity.

The previous examples illustrate how patterns of sociotechnical change can provide entrance points for modulation. In the next paragraph we focus more specifically on some of the patterns of niche and regime development in order to set the stage for a final paragraph with suggestions for modulation of sociotechnical change towards a less carbon intensive electricity system.

6.5.2 Ongoing developments in the electricity system

In order to structure this section we will start by sketching the core of some directions. Developments in the electricity system can take along two major dimensions in the electricity system: level of centrality and level of scale. Table 6.1. provides an overview and gives for the four quadrants the major technologies. Moreover, in each quadrant an indication of the dominant actor is given in a situation of full liberalisation, which at this moment is not yet fully realised, but is expected to determine interactions in the electricity system for the decades to come.

Large scale and central electricity generation (upper left quadrant) signifies the central station electricity model that has been dominant in this century. Fossil-fired power plants have been the main technology, but also nuclear energy fits in this path. This path is essentially following the guiding principles of the electricity regime as we have described it in the earlier chapters. Embarking on this path in dealing with climate change implies some modifications of the system, but essentially reflects the belief that the current electricity system is perfect and should be maintained. The various options of dealing with climate change with current technologies are: storage of CO_2 emissions, increase of nuclear energy, use of coal through coal gasification with CO_2 storage. In chapter three we argued that actors in the electricity regime are most likely to share these beliefs. The sense of urgency these actors have regarding the climate problem is relatively low, action should only be taken when the climate problem is validated and through international co-ordination, implying first measures by modernising technology in developing countries and through joint implementation.

At the sociotechnical landscape level the effects of liberalisation are pervasive on the central station electricity system. The central station model is now moving towards the European level and central producers have changed from a national to international orientation. Further reinforcement of the transmission network is one of the logical consequences of this tendency, and import capacity therefore is an important issue. Both nationally and internationally the electricity system in the short term is characterised by surplus capacity and increasing competition. Producers are very hesitant to invest in new facilities because of uncertainties in demand, policy developments and technological paths. The dominant trend is that any investment in power plants is one where flexibility, relatively low capital costs, and cheap electricity generation are crucial elements. The technology that fits these criteria best currently is the combined cycle gas turbine. In their struggle for survival, climate change concern is not a major priority for central producers, and is dealt with in the context of safeguarding continuity. Action regarding CO_2 emissions will only be taken if refraining from action will threaten this continuity. An example is the producer’s strategy for their coal-fired power plants, which, after threats closing them down by the Dutch environmental minister, are now increasingly co-firing with biomass in order to improve the emission profile. While the agreement on benchmarking, concluded at the end of the nineties, will probably have some positive effects on efficiency, it is unlikely that it will have a major impact in the light of the problems the Netherlands faces to realise its Kyoto targets. Moreover, while CO_2 storage is still available as a last resort, its feasibility is still uncertain while producers are unwilling to invest in experiments. Asserting real pressure on central producers will most likely therefore only be feasible through the introduction of a CO_2 cap, for example by introducing emission trading.

Table 6.1 Main directions for electricity generation and use

	Central electricity generation	Decentral electricity generation
Large-scale power plants	*Central Station Electricity Model* Supply oriented Fossil-fired power plants Nuclear energy Biomass (co-combustion, combustion, gasification) Waste incineration Off-shore wind energy Dominant actors: producers, government, distributors	Demand oriented Industrial combined Heat and power production Dominant actors: Industrial companies
Small-scale power units	Coal/biomass gasification Biomass fermentation Biomass pyrolysis On shore wind parks Dominant actors: Government, R&D institutes	Mini and micro CHP Fuel cells PV technology Micro turbines Wind turbines Biomass systems Dominant actors: Consumers, Equipment producers, new actors *Distributed Generation Model*

The large scale integration of alternative sources into this current technological configuration also fits this path. This includes large scale application of wind energy (e.g. off-shore wind parks), large scale biomass co-combustion, biomass gasification, and large scale PV technology (e.g. import of PV electricity from Southern regions). Currently, off-shore wind energy is the only option that seems to be feasible in the short term and the Ministry of Economic Affairs is actively pursuing this path. In order to avoid being overly optimistic and ambitious we think that the role of the Ministry is one of facilitating this development, not determining it, by laying some ground rules in terms of procedures (locations, permits) and safeguarding continuity of purchases (green certificates, public procurement, minimum prices). Most importantly these projects need a process of interaction between a variety of actors, both national and international that will determine the economic, technological and societal feasibility of these projects. Experience with large wind turbines off shore is still limited (with some experience in Denmark and Sweden), and accumulating experience will be a key to successful implementation of such a project. One of the main prerequisites for this type of projects will be the establishment of a guaranteed market for renewable energy with acceptable price levels.

In the lower right quadrant the opposite development of the electricity system is signified. This is now known as the distributed generation model. This model is characterised by power systems that offer power close to the customers, rather than building transmission lines and distribution facilities to move electricity from central power plants to consumers (Smeloff and Asmus, 1997). The systems are designed on specific local or regional demand for electricity, sometimes connected to specific buildings, industries or neighbourhoods. This technological path emerges because the conventional wisdom that large central stations are the most economical to provide power to customers is shaken by the advent of smaller, efficient gas turbines (Flavin & Lenssen, 1994) and the emergence of fuel cells (Lovins & Williams, 1999; Romm, 1999). Fuel cells in some cases already serve a market niche, such as in the USA where the First National Bank of Omaha has installed four 200 kW fuel cells because they wanted to install the most reliable power source they could find to prevent power interruptions (Romm, 1999: 128). The distributed generation system also offers opportunities for the development of renewable sources such as wind turbines and photovoltaics that can be connected with micro co-generating units. Most renewable energy options are well suited for local application at a small scale (Cogen, 1999). An advantage of the distributed generation system is that it reduces the amount and cost of transmission and distribution. Proponents argue that the grid is costing too much, and small systems can be more efficient and environment friendly (Cogen, 1999). The emergence of local based systems would mean a development towards a much more diverse system, whereas the real-time fine-tuning of supply and demand is within reach through developments in information and communication technologies.

Strategies from various actors converge with the development towards a distributed generation system. In a liberalised market, consumers have free choice of electricity providers and can become both electricity user and producer. Developments in California have shown that in liberalised market with a pluralist arrangements, issues like reliability become reframed, and customers have to deal with reliability in a much more direct way. The tendency will be that consumers move from passive to more active, with the scope of leading edge consumers moving towards own electricity generation. Power equipment producers are developing small scale generating systems with increasing efficiencies. An energy strategist like Amory Lovins expects fuel cells to become five to ten times more cheap that conventional combined cycles gas turbines (Lovins and Williams, 1999). Clearly, promises and expectations regarding these new electricity generating technologies are high. Yet, the number of actual projects in which technology providers, users, infrastructure developers, distributors of gas and electricity, and construction companies work together to experiment with these new systems is limited. Moreover, knowledge regarding aspects of systems integration of various technologies and the use of information technologies to control and operate the system is still limited.

The upper right quadrant indicates large scale decentral electricity generation and mainly includes self generation from industries. Decentral CHP has especially gained momentum since the combined cycle gas turbine made inroad in the electricity regime. This development has also paved the way for the further shift of the gas turbine towards smaller scale as indicated in the previous section. This is a development trajectory that differs from most technological trajectories in electricity generation where technologies are first developed at small scale and then progress to larger scale. This has been the trajectory for the steam turbine, while a similar trajectory has been set in motion for coal gasification and biomass combustion. There first applications took place in the lower right quadrant. Wind energy is following a similar trajectory with the development towards offshore wind parks with large-scale wind turbines.

6.5.3 Suggestions for modulation

The previous chapters have suggested that the electricity regime is in flux. The dominance of the fossil based central station electricity system is being challenged both by a range of alternative electricity generation technologies and by a variety of actors that have adopted strategies that diverge from its dominant principles. In this dynamic setting we present a set of recommendations in order to take into account the multi-actor and multi-level character of sociotechnical development in the electricity domain. While our set of recommendations draws from work from various scholars of sociotechnical change (e.g. Bijker *et al*, 1987; Weaver *et al*, 2000; Kemp *et al*, 2001; Schot, 2001), it aims to translate some of the general lessons from sociotechnical change theorists towards the electricity regime. Moreover, we also draw on some of the work on the transition towards an emission free energy system (Rotmans *et al*, 2000; van Hilten *et al*, 2000).

- *Develop vision and goals from a sociotechnical change perspective*

Goals have often been framed from a single technology or single policy perspective. An example is the target for wind energy that has been set in the past. From a sociotechnical perspective several problems can be identified in wind target setting in the past. In the first place the process has been of a too technocratic nature based on what was technologically feasible and not on what could be societal feasible, and secondly the target was set at the national level and not translated to the local level. Participation of a broad range of interested actors is therefore one aspect of setting targets from a sociotechnical change perspective. Another aspect is the way these targets are framed. Realisation of these targets involve a process of sociotechnical change that extends the development of a single technology but also involves, for example for wind energy, the integration in spatial development and in zoning procedures and societal aspects such as citizens' perception of wind energy. In order to signal the nature of this process it is useful to translate these targets in sociotechnical goals. Examples are targets for the realisation of sustainable neighbourhoods and sustainable industrial estates.

A third aspect concerns the integrative nature of developing a vision from a sociotechnical change perspective. Climate policies have until now often taken place separately from other policies. Yet, the transformation towards a carbon free electricity system necessitates the integration of climate policy in various policies, such as those regarding spatial planning. In discussions regarding spatial planning opportunities for PV and wind power can be taken into account at an earlier stage. One example is the development of industrial estates with pre-established allocation of zones for wind turbines, in order to facilitate the actual procedure for installing the wind turbines. Another example is the set up of experiments with the distributed generation model in the various VINEX locations that are in development. Apart from integrating policies of various departments the development of shared visions within and between various departments is relevant. Moreover, climate policies have until now been dominated by national policies. Articulation of the problem of climate change at the local level is crucial, for example by setting goals for renewable energy at the local level.

- *Broaden technology policy*

With regard to technology policy our analysis has shown that these policies have generally been too much of a top-down nature, with a strong focus on technologies, and a weak focus on interaction processes of actors. As was shown in chapter three the organisation for energy

R&D have their roots in the seventies and eighties, in a period that the fossil-based electricity regime was dominant. The tendency is to organise energy technology development in a basically linear fashion (from development, to market introduction, to regulation) which only allows for evaluation of social aspects when the technology has materialised. To counteract this "the design of technological development should be a broader, interactive process including a variety of societal actors in addition to technical experts" (Schot, 2001: 41). This conclusion plus the observations that the Dutch R&D organisation has a primary national focus while momentum in the electricity system is occurring at the international level and local level ask for an reorientation of energy oriented technology policy. Firstly there is a need for a stronger focus on the local level. Now allocation of R&D takes place almost exclusively through national channels (Novem, Senter, ECN, Kema, TNO). To facilitate local design processes of technologic development it is necessary to accompany this national structure by an organisational structure where the local level plays a prominent role. Secondly, whereas technological development already is an international affair, with the main developments in energy technologies coming from abroad, technology policy can further enable connections with international technological developments, and promote the creation of international alliances.

- *Stimulate systems approaches and develop competencies regarding alternative systems*

Our analysis has made apparent 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. It often involves a two-way flow of electricity with a larger number of relatively small units, discontinuity plays an important role, etc. Moreover at the user side also the development towards smarter (metering) equipment can be witnessed. In order to facilitate these developments and enhance their chances of establishing environmental friendly development paths and systems this asks for a stronger focus on systems instead of on individual technologies. However, both fundamental as well as practical knowledge regarding systems integration is still limited in the Netherlands and could be stimulated both at universities and research institutes.

- *Develop alignment strategies for the development of coalitions of actors from various sectors/regimes*

The successful examples of decentral CHP and green electricity have shown how alignment between different actors can create momentum for more environment friendly concepts. Also the development of PV has shown the importance of collaborative networks. Therefore, social networks are key elements in the stabilisation of present technologies but also in the creation of new ones (Weaver et al, 2000). These networks often cross borders of policy fields, sectors and regimes and derive their potential from that. Actors in the waste regime (and also agricultural regime) are involved in technological development (e.g. biomass fermentation, gasification, pyrolysis) in order to serve various goals: closing material streams and reducing CO_2 emissions. Gas utilities that used to provide heating services to households and now are developing micro CHP systems that provide electricity and heating, based on gas input. Both networks can benefit from stronger local and user participation. Incentives could be developed to stimulate closing of material cycles at the local level, and to develop local based energy systems. The role of government can therefore be one of an alignment actor, by creating the right incentives and fora in which new coalitions can be formed and developed.

- *Exploit shifting actor strategies, heterogeneous demand patterns*

The electricity regime is opening up in several ways. The electricity market is moving both towards much higher differentiation and fierce competition and these two forces will have a very significant impact on the electricity system. In the first place previous stable and closed actor constellations are changing. New actors are able to enter the regime by providing electricity or by acting as a trader or service provider. In the second place there is now scope for new products, such as green electricity, or electricity services connected to electronic equipment. In the third place consumers now have various choices and can establish their own contracts with electricity providers. This implies that the role of marketing has become crucial in strategies of energy providers, and new companies entering the energy market may have more experience with regard to marketing than the established energy companies. Finally, there is now scope to attract customers by providing electricity tailored to their specific demand. This also gives potential for the application of and experimentation with energy technologies which characteristics are better suited to specific demand characteristics. Examples are fuel cells that can provide high reliability, modular energy technologies that can reduce transport need; energy technologies that are flexible with regard to construction, production and investment; energy technologies that combine various functions by providing power and heat and closing material cycles.

Apart from having an effect on providers of electricity, consumers themselves will also be affected by the changes in the electricity market. The consumer will start to think about the electricity product and service it requires. While most households may not even consider changing the contract it will automatically receive when the electricity market becomes free, some ‘leading edge’ consumers may consider the various alternatives of electricity provision. These consumers are the ones that will be targeted by providers that offer new kinds of electricity services and contracts. Ongoing developments include the formation of consumer groups that have more bargaining power opposite electricity providers. Also new actors like traders of electricity will play a role as a chain in electricity generation and use.

Strategies can also profit from shifts in consumer preferences, for example by promoting (the marketing of) houses with photovoltaic panels and its positive environmental image and by combining them with changes such as the greening of the tax system. PV technology is clearly costly relative to other generation technologies. However, PV technology may become more attractive due to the positive green image that is attached to a house with PV panels, while it is a relatively small cost category compared to the total costs of a house. In order to generate some momentum with regard to further penetration of PV technology, the need for standardisation of PV panels in roof construction has been expressed (Sinke, 2000). Strategies could aim at creating coalitions between PV developers (such as Shell) and construction companies in order to produce prefabricated roofpanels with PV.

- *Promote learning processes at local level*

Experiments will foremost take place at the local level with interaction of producers, intermediaries and users. Both energy policy and technology policy dominantly have a national orientation. The general picture is that users more specifically should get a role in experiments. Governmental agencies could then engage in sociotechnical alignment policies and process management, where the role of the government is that of an alignment actor, a matchmaker and facilitator of change rather than that of a sponsor or regulator (Rip and Kemp, 1998). An important development in the electricity system is the development of decentral small-scale systems, a development that could be facilitated by carrying out experiments at the local level with a variety of relevant actors, such as municipalities, real estate developers, electricity companies, electrical equipment producers, construction companies and users.

- *Explore and exploit linkages between the sociotechnical landscape, regime and niche level*

Also several developments in the sociotechnical landscape can play a role in the transformation of the electricity regime. The development in information and communication technologies (ICT) is an example of this. It holds promises for consumer based real time monitoring of energy use, e.g. facilitating the switching on and off of systems at moments when electricity is relatively expensive or cheap. It will also play an important role in the operation of a system of distributed generation.

The fast emergence of ICT companies also creates opportunities for experiments with distributed generation. Due to the fast growing concentration of ICT companies in the Southeast of Amsterdam, at the end of 1999 the capacity of the grid became insufficient to be able to distribute electricity to new companies. Electricity demand had risen sharply and unexpectedly as ICT firms have chosen Amsterdam as favourable location for new investments and they use substantial more electricity compared to other types of firms[111]. ICT firms choose Amsterdam because of the interchange of the transatlantic glass fibre cable located there and because they wish to settle down close to each other. The firms and distributor try to solve the problems by expanding the grid but this will take six months to three years.[112] ICT firms are now hesitant to settle in Amsterdam, because they need guaranteed electricity services, and are depending on the extension of the grid. In a fully liberalised market, and with the development of small scale generation technologies, they will be able to develop small scale, local or in-house, generation systems which could very well suit the electricity demands of these firms, thus combining niche development and landscape developments.

At the regime level it is important to translate the urgency of the climate change problem more specifically to the regime. One of the most direct policy measures with regard to this is the emission cap applied through a system of emission trading. Because of the increasing importance of European legislation agreements made at the European level will play an important role. Moreover, a significant aspect is how liberalisation will be dealt with in the electricity market. It can lead to the import of relatively cheap electricity from foreign countries, electricity that is sometimes generated with much more CO_2 emissions. Also the

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[111] According to Nuon, the distributor, ICT firms do use 1000 watt per square meter compared to 50 a 70 watt per square meter by ‘normal’ companies (ANP, 22 September 2000).
[112] Sanders, R., Stoppen slaan door bij ICT-bedrijven, Stroomvoorziening groeiend probleem in Silicon Valley en Amsterdam, *Computable*, juni 2000, nr 25, pp. 7

reduction of CO_2 emission in the electricity sector in 1999 is a result of increased imports. Thus decisions regarding the development of import capacity can have important effects on the allocation of CO_2 reduction. Increasing import of electricity may increase the substitution of fossil based sources for renewable ones. If electricity demand is taking off again, another option is to link growth of energy use of companies to use of renewable energy. These kinds of strategies are even more relevant because the surplus capacity in the Dutch electricity system hampers the extension of the share of renewable energy. Moreover, the increasing freedom of choice for consumer offers opportunities. Until now government has mostly influence the electricity supply side of electricity generators and distributors. While direct interference at the supply side may be more problematic with liberalisation, regularly proposals can be heard to oblige consumers to buy a certain share of renewable energy.

Another development that has already proven to have impact on the electricity regime is the greening of tax system. There is scope for further, more differentiated, greening of the tax system to promote more environment friendly energy options relative to others. This should be accompanied by larger transparency regarding the origins and environmental profile of electricity flows. The development of green certificates and certificates with environmental profiles of generated electricity is one possible mechanism to increase the transparency of international electricity flows.

- *Prevent that too much focus on short term leads to lock out of promising longer term options*

A significant part of Dutch government efforts is focussed on the path of large scale renewable energy development, especially large scale wind energy and the development of biomass applications. Various generic (market conform) instruments, such as the regulatory energy tax, and the exemption for energy produced with renewable sources, stimulate the application of renewable energy technologies that are currently most competitive and fit the current electricity system. However there is also a need for the use of specific policy instruments to enable the implementation of various experiments for promising technologies that can not easily adapt to the current technological configuration, and for which a new technological and social constituency has to be developed. Too much reliance on market conform measures may therefore decrease the willingness to invest in riskier technological trajectories that have long term potential for a carbon free electricity system.

- *Identify and stimulate potential key enabling technologies*

Key technologies are those technologies that have potential to penetrate various domains, or those technologies that can enable the application of other technologies. Examples are energy storage technologies. Development in storage technology can lead to changes in preferences for electricity generation technologies, and can make some of the discontinuous renewable generation technologies more attractive. A second example is the development in information and communication technologies (ICT) that is relevant for the electricity system because on the one hand facilitates more flexible control of supply and demand, and on the other hand it is an important factor in the ongoing process of electrification of society. Another example is the fuel cell. The fuel cell combines several domains and concerns not a single industry, such as wind, but one that can penetrate several industries, and is being driven by various industries such as automobile industry, power industry, gas industry, space industry. The number, scale and diversity of actors involved in fuel cell development is large. These actors are now mostly scattered, and use different designs with different problems associated to them. The number of coalitions in fuel cell development and application is however increasing. There is a variety of applications for fuel cells, from power generation to power and heat production in buildings to powering cars. In power generation there is a variety of potential consumers with current market niches for highly reliable power and potential market niches for combined heat and power production for hotels, small neighbourhoods and industries. Spin off of learning from one application to other is visible in fuel cell development. There is potential for hybridisation with various technologies and fuel sources. Examples are turbine technology (already visible), and with renewable options (a) through production of H_2 by electrolysis with wind and PV b) through production of H_2 from biomass (through gasification and production of syngas, other technologies).

- *Focus on potential transition paths, identify bottlenecks for patterns of niche cumulation and hybridisation*

At the niche level it is important to initiate and facilitate processes of niche cumulation and hybridisation. The introduction of small scale generating systems such as fuel cells and microturbines is mainly a move towards decentral cogeneration with relative high efficiencies, but it can provide a stepping stone towards more inherently climate friendly electricity generation methods. Fuel cells do not produce CO_2, only when in a preliminary step natural gas is reformed towards H_2, emissions of CO_2 occur. Moving towards other inputs for H_2 production, such as syngas, methanol, or water, holds the promise of CO_2 neutral electricity generation.

Moreover, the distributed generation model can integrate various renewable energy technologies in the system. For example for wind energy the development is now towards efficient turbines at low wind speeds. This offers also opportunities for the application of small-scale turbines with relative low height to reduce horizon pollution. The dominant focus is now towards the development of larger scale wind turbines, especially for offshore energy production, but further development of the wind turbine may therefore also open other routes that were previously considered less promising.

In sum, our analysis and the recommendations for modulation aim to increase understanding of the dynamics and patterns of sociotechnical change that inform where opportunities exist to trigger new actor linkages and alignments which can enable the creation of new transformational paths.

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Appendix 1 The development of nuclear energy in the Netherlands

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 also 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 it did very well fit thinking in terms 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.

The first actors involved in nuclear power were the generation companies, which viewed themselves as mainly responsible for the construction of nuclear plants. They started to gain the necessary knowledge by means of the joint research institute of generators, the KEMA and researched the developments in other countries. (Especially the US had an enormous head start over all other countries.) This can be seen as the start of the learning processes, because the actors had not gained any routines yet. 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.

In 1955 the government established a special national research institute for nuclear energy, Reactor Center Netherlands (RCN[113]). 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 even managed to supplement their nuclear research with funds from the government and Euratom (the European Atomic Energy Community). The technological principles researched by the KEMA[114] differed from the principles researched by RCN. So at that time there were two research programs for 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.
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 government budget for R&D in that period (Lagaaij & Verbong, 1999). Much of the government efforts were directed towards the build-up of a national nuclear industry.

The reactor type of the KEMA had some advantages over other technologies in the field, but also a technical disadvantage, which couldn't be solved, despite the intensive research and investments. The generators have built a test reactor, but at that time it was acknowledged that a prototype reactor would not be constructed. This was because of the high costs, the lost support from Euratom, the withdrawal of industry's support and the choice of Dutch government for two other reactor types. Still the generators had the idea that knowledge of all the technical, economical and organisational matters that

[113] Later this institute has been renamed in Netherlands Energy Research Foundation (ECN).
[114] The KEMA researched from 1951 the development of a Suspension Reactor (SR).

arise when exploiting a nuclear plant was needed, so it was decided to buy different technology from another country.

Because it was the generators that decided what power plants have to be built, the RCN had no influence any more on the chosen technology for nuclear power plants. The Dutch government, at that time strongly in favour of nuclear technology in general, also had no real influence on what kind of nuclear technology should be used in nuclear plants, due to lack of (legislative) steering instruments.

Because of the cost, generators decided to buy a smaller plant than planned, which they should be able to use for research also. This made it possible to get new funding from Euratom. The SEP did not see much in the perspective of the involvement of Dutch industry[115] in the construction of (parts of) the reactor (Lagaaij & 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, GE and Kraftwerk Union, were the main partners. Industry was only involved in providing parts for the first Dodewaard reactor, but the know how 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 by a foreign company, and built in Borssele in 1973. This plant was based on the pressurised water reactor technology. The behaviour of generators can be described as risk avoiding, by buying a plant based on proven technology, the strive for external funding and decreasing the size of the first plant.

The national government was not able to change the course of the events, because of the autonomous position of generators[116]. The variation of technological alternatives emerged from the research institutes and from the foreign companies. In the selection process for the construction generators were the only actors that played a role, although other actors wished to participate in this process. In 1974 it was therefore decided that the decision-making competence with regard to building new nuclear power plants should be assigned to the Ministry of Economic Affairs.

Citizens, as a part of the social component of the selection environment, in the seventies came into play with protests. A rising public concern for safety, the problem of the nuclear waste and proliferation of nuclear arms had begun world-wide to emerge. This social resistance in the Netherlands became organised. So strong the Dutch government was forced in 1978 to organise a national debate (BMD) about nuclear energy that was ended in 1984 with a final report. In the national energy debate on future energy options, nuclear was among the most unfavourable options. The debate was decided beforehand because the science community was pro nuclear and was supported by national energy policy and the electricity industry. Despite societal resistance, but in line with the resource diversification orientation in national energy policies, the Dutch government approved 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 happened. The social environment rejected nuclear energy as a technological regime again. Because at that time the selection of the usage of nuclear technology had to be made by the government, they decided to postpone the authorisation, although it was suggested that there was no connection with the accident. At that time it was possible to take such a decision. The consumption of publicly generated electricity was not rising because of the energy saving policy based on environmental reasons. Moreover, 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

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[115] Various industrial actors formed a consortium called Neratoom in 1959 to jointly develop expertise for the construction of nuclear reactors. Companies involved were Philips, Stork, Werkspoor, RDM, de Schelde, Machinefabriek Breda, NDSM, Wilton Feijenoord and Comprimo.

[116] Although provinces or municipalities owned the generators, they acted like private companies.

1987 nuclear power has no longer been a serious option for power generation, and Dutch parliament decided to phase out nuclear, by terminating the only Dutch nuclear plant still in operation, in 2004.

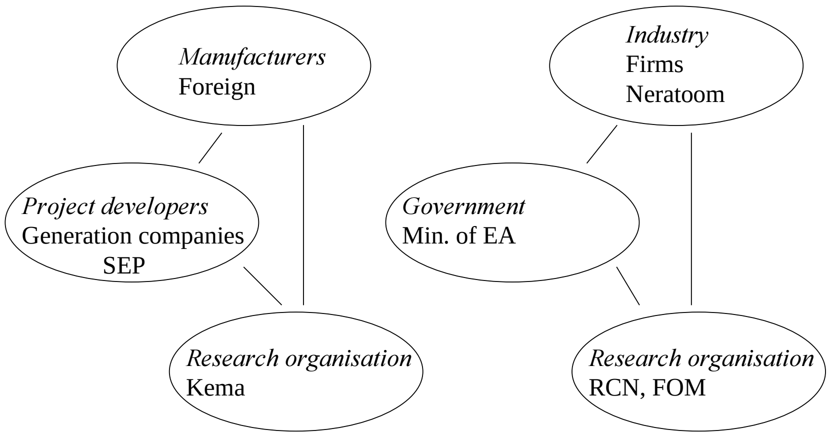
The development in opposition and even the fact that there was opposition at all at such a large scale has been unique for electricity generation. The nuclear discussion, broaded by the government in 1983/4 by the BMD in a discussion concerning all electricity generation technologies, involved thousands of citizens that before never participated in discussion like this. It also was a unique step from the government that never has been repeated for what kind of topic at all. As an instrument to reduce societal concern with respect to the proposed extension of the use of nuclear energy the BMD failed and the general opinion was opposing nuclear energy.

However, still some groups, also in government, are still in favour of nuclear energy. In 1993 the Ministry of Economic Affairs presented the Nuclear Energy File in which nuclear energy was presented as being safe and as a remedy against the greenhouse effect and with soluble waste problems. The subsidies for the NCR continue even nowadays, although in recent years the nuclear research in the Netherlands at FOM and NCR has changed to fusion reactors. This new technological principle is researched form the sole initiative of the political component.

There have been built only two nuclear plants for power generation in the Netherlands. The electricity production has never exceeded more than 8,5% of the total public generation of electricity. Compared to other countries this a very low share. The average amount of nuclear-based electricity in the EU is 26%.[117]

For the decision and construction of the two nuclear power plants for electricity generation built in the Netherlands, the electricity sector was the single actor. They managed to leave out government and her research organisation, as well as Dutch industry. This although these actors were active in R&D on nuclear energy and willing to be part of the actual building of the power plants. In the next figure the different actors and their relations are pictured.

Figure 1 Actors in development and research of nuclear energy until 1974



The dominant actors have been in favour for nuclear power for a very long period. The sector, government and industry considered nuclear power necessary and a viable option. Although there was agreement on the need of nuclear research, there was no consensus on the technological principles to be researched. Because of this institutional embeddness of the technology research has never been achieved. All actors believed that nuclear technology would be very profitable in the long run and wanted to gain experiences with this technology. The nuclear technology domain emerged therefore because of the broad support from government, industry and generators. But from the start a difference

[117] Van Engelen et al., 1993, pp. B1000.

could be seen in motives driving the efforts of generation companies and the other parties involved. For both the Ministry and the industry one of the main motives was to obtain a position on the international nuclear market. To reach that goal, the industry was willing to co-operate at the national level to a certain extent. For the generation companies however this was clearly not the case and they decided to try to develop nuclear technology on their own for solely their own purposes and by doing that frustrated industries efforts to establish a national nuclear industry. Both groups of actors did operate independently and in the end the generators made the selection of the type of nuclear technology used for building power plants.

During the seventies and eighties public resistance against nuclear energy grew. In the national debate for energy options it was clear that the opinion of the public towards nuclear energy was negative. New actors had entered the regime with new demands for characteristics to judge technologies with (or technology performances). For these actors the (niche) position of the nuclear technology was of no concern and they were even willing to change the fulfilment of the social function of electricity, by reduction of electricity production (through energy saving). The Chernobyl accident brought this group of actors that had not been involved in electricity generation in early stages, in the selection process. After the change in attitude and involvement of new actors in the social component of the selection environment, nuclear technology did not meet the demands of the environment sufficiently and therefore did not survive the selection process. The rejection force of the social component was overwhelming compared to the other components. Just because of the emergence of strong social opposition the politicians rejected publicly the nuclear technological regime and no nuclear power plants have been built anymore. (But nuclear research has never been stopped.) It was possible to make such a decision, because the wide held belief in the necessity of nuclear energy became less strong. Several developments account for this. The world energy reserves turned out to be much higher than expected in the fifties and sixties. Energy saving policies, based on environmental reasons, led to a lower increase in electricity consumption as expected and the costs of nuclear power were estimated much lower as they turned out to be

By stimulating two different lines of nuclear research, the government failed to establish a single technological innovation network. Because of the legal impossibility to decide on the building of nuclear plants, the government was not in the position to influence the selection of a certain type of nuclear technology. After this became legally possible, the social environmental component adjusted the political situation and prevented by this the establishing of a nuclear technological regime[118].

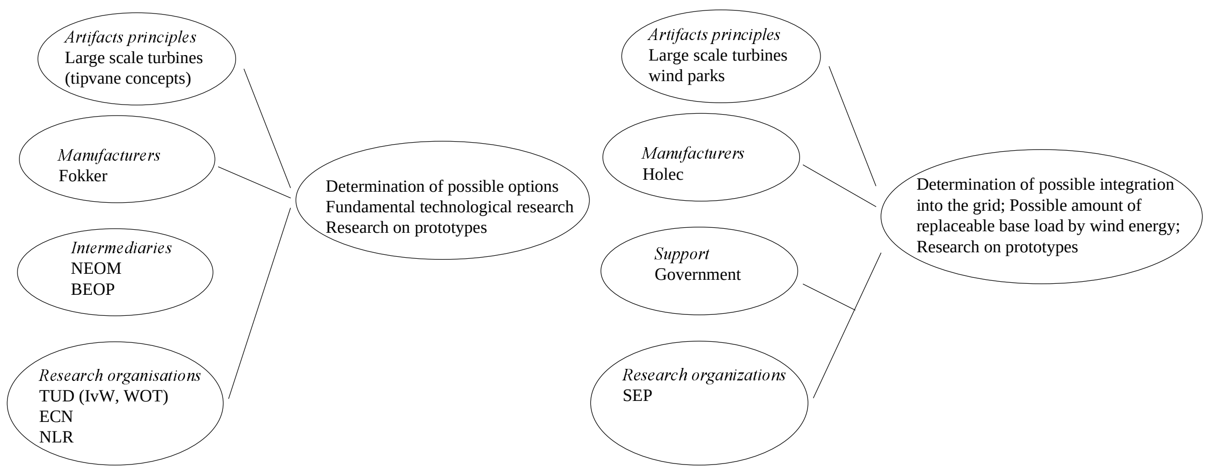
118 Though not discussed in this paragraph, uranium enrichment by centrifuge has turned out to be a rather successful technology domain in the Netherlands. It can be regarded as spin off from the former nuclear research.

Appendix 2 The development of wind energy in the Netherlands

Overview of developments

Historically, the Dutch have ample experience with the use of wind energy. In the 19th century wind was the dominant power source in industry, and some 9,000 windmills were estimated to be in operation with a total capacity of 300 MW (Gipe 1995: 122-123; van Kuik 1998: 2). Already in the 16th and 17th century windmills were crucial for shipbuilding and for land reclamation by impoldering (VDEN, 1980). However, in the development of the electricity system wind has long not been considered as a source for power by the authorities. This changed due to the oil crisis in 1973. Due to the expected shortages of fossil fuels, wind was from that moment seen as one of the alternatives for electricity generation. In the 1974 White paper on Energy, in which conservation and diversification of energy sources were central principles, it was acknowledged that wind energy could have a role in the future. Because for the short term nuclear power was considered the only alternative for fossils and because of the limited potential of application of wind power at that time (because it was not well enough developed) it was decided to support research. For this support two new organisations were established, the LSEO and NEOM. The LSEO reported in 1975 that wind energy was on of the most promising renewable energy options and in 1976 a national research program on wind energy (NOW-1) was set up (Van Zuylen et al, 1999, pp.18), followed by a NOW 2 in 1981.

Figure 2 Dominant actors in research, NOW 1 and NOW 2



From the side of the actors involved in research or support, the role of the government was important. Central government tried to co-ordinate and stimulate the development of wind energy by establishing a number of organisations. The first organisation established was the LSEO that was supposed to put together a research program. The second organisation, established by government, was the NEOM. This organisation was supposed to support implementation projects. To do so it among other things tried to diffuse knowledge, by transferring knowledge from the ECN and NWO to industry. For to co-ordinate and manage the NOW 1 program a new organisation, BEOP, was established at the ECN (named RCN at that time). In later years the different organisations do merge into Novem.

Besides the activities within the framework of the NOW program there have other research efforts in wind energy development. These efforts aimed at the construction of small turbines for water pumping that could be used in developing countries. Actors involved from 1972 / 1973 were the University of Delft and an environmental group and from 1975 on a consultancy service (CWD)[119] and a manufacturer of wind turbines. The manufacturer did produce wind turbines for power generation. The Ministry of Foreign Affairs financed the CWD program that was terminated in 1990. According to Verbong actors involved in small wind turbines managed to create a new line of research directed towards small-scale autonomous applications within the NOW program (Verbong, 1999, pp. 146). But the share of the total budget for decentralised applications has been small.

The second program (NOW 2) that aimed at large-scale applications led to in the beginning of the eighties to the government decision to develop a demonstration prototype of a wind park to be operated by SEP. This involvement of the central producers in wind energy opposes the observation that central producers have not be involved in sustainable generation at all. The wind-park encountered unforeseen problems.[120] Initially the energy sector expected that wind turbines would technically not give too many problems. However, the set up of a wind park made clear that the scaling up of the wind turbine leads to several problem areas:

- strong vibrations that the turbines have to deal with;
- the nature of wind as a very unstable source of energy (a large source of unrest)

The gained experiences seem to have been disappointing though, because the SEP never has been involved in wind energy again.

From 1980 on the national government provided tax credits for instalment of wind turbines (van Zuylen et al, 1999, pp. 19) but until 1986 hardly any wind turbines were installed. The energy account act at that time (WIR ET), implying a tax credit on investment, did not contribute to realisation of new wind turbines. It was concluded that spatial integration of wind turbines could be a hindrance for the diffusion of wind energy and in 1985 the goal for the year 2000 was decreased to 1000 MW (Wolsink, 1996). From 1986 until 1990 the Integral Programme Wind Energy (IPW) provided the first subsidy for wind turbines. The program aimed at instalment of 100 - 150 MW of wind capacity in 1990. As it turned out the budget of the program was used to support industry that faced troubles at that time due to low energy prices (Verbong, 1999, pp. 153). In 1991 the program was followed by a new subsidy, the Implementation of Wind Energy in the Netherlands program, TWIN-1.

In 1990, as a result of the NEP and tasks imposed for the energy supply sector, utilities reacted by formulating their Environmental Action Plans (MAP). Part of the plans was to stimulate wind energy, with as goal an extra 250 MW installed by the year 1994 (Wolsink, 1996). This plan though never was executed and stopped in 1993.

Central government kept on supporting wind energy through the years. In 1990 a new research program, as successor of the NOW, was started by the national government, the Implementation of Wind Energy in the Netherlands, TWIN-1. In 1996 this program was followed by TWIN-2 (van Zuylen et al, 1999, pp.18). To dissolve problems with spatial integration in 1991 government and the seven windy provinces reached an agreement, the Management Agreement on Wind Energy Location Problems to reserve space for wind turbine sites.

The wind capacity starts to rise more quickly and reaches a top in 1995. According to van Zuylen (et al, 1999, pp. 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. Potential investors in wind energy hesitate to invest and as an effect the growth in new installations decreases. 1995 turns out to be the year with highest increase in wind energy capacity (100 MW) what is twice as high as in the

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[119] Consultancy Services Wind Energy Developing Countries (CWD).
[120] Personal communication with Ir. A.J.M. de Keijzer, former employee of Electricity Distribution Company EDON, April 2000.

years to come. But also another aspect had an effect on the installed capacity, this is the long preparation period needed to install wind turbines (see below).

Technology

According to Beurskens and Janssen (in van Engelen, 1998) the choice for the number of turbine blades was not based on technological or economical arguments. Three blades are favoured over two blades because of the lower noise production and the more positive attitude of the public towards three blades. This latter as an effect of the more quit appearance of the turbines in the landscape.

Another variable aspect in turbine designs is the use of a gearbox or not. This is determined by the choice foe a direct drive generator or variable revolutions. Direct drive is more inexpensive, but lacks benefits as higher energy yield, lower noise production at low speeds and improvement of load quality (Beurskens and Janssen (in van Engelen, 1998). Most turbine designs therefore use gearboxes.

Wind technology is not considered a mature technology yet, because of the rapid developments in cost reduction, offshore technology, exploitation at lower wind speeds and public acceptance. [121]. These developments are supposed to continue in the future.

The performance of wind technology

The slow diffusion of wind energy is remarkable. The Netherlands has originally been considered one of the frontrunners in the development of wind energy, together with Denmark and Germany, but this position has weakened in the eighties due to stagnation in development and market introduction. According to Wolsink (1996) these two reasons are linked. He comes to the conclusion that a number of policy measures and choices have not been effective to stimulate wind energy: The reliance on large-scale application, stimulating capacity instead of energy yield, entanglement of energy policy and industrial policy and the process of obtaining sites. Because of all these obstacles and miscalculations, wind energy has not become economic feasible, hindering the mass production of turbines, which in return hindered economic feasibility, etc.

Also other use the complex of mainly economic and financial factors to explain the disappointing development. Currently, the shortage of locations for wind energy is considered to be the main problem hampering wind energy development and introduction (Ministry of Economic Affairs, 1999c). 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 acoustic noise and by this do not meet the expectations (or goals) of actors involved.

For to deal with the major hindrance for wind energy, the spatial integrating, the scaling-up of wind turbines is a possibility. There are two ways to accomplish this. The first way is to build a larger wind turbine on a spot for which permission has been given. When we look into the average capacity of the installed wind turbines of 1996 and 1999 it is shown that this capacity rises (see table xx). Dutch researches work together in development of a wind turbine with a capacity of 5MW that should be ready for demonstration in 2007 (ECN, 1999, pp. 60). The increase in the scale of wind turbines available (see chapter 3) therefore does match the goals of the actors that want to install a number of wind turbines or better to say a certain capacity of wind energy[122].

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[121] Website ATLAS Project. Project undertaken by the European Network of Energy Agencies on behalf of the Directorate General XVII (energy and transport) of the European Commission (http://europa.eu.int/en/comm/dg17/atlas/html/wind.html).

[122] Because for individual installations a larger turbine is not likely to decrease opposition.

Table 1 Installed wind turbines in the Netherlands

Turbine capacity (kW)	75	80	225	250	300	400	500	600	660	750	1000	1650	Total number	Total (MW)	Average (kW)
1996	1	36	20	4	8	2	21	42	-	1	4	-	139	52.425	377
1999	-	4	-	7	2	-	3	22	20	13	1	7	79	52.815	668

Source: Web-site Wind Service Holland, 2000

Government stimulated the increase in capacity. Subsidy schemes for wind energy have been directed at the installed capacity. The effect was that there was less incentive to improve the performance of the turbines. In the next table the progress in the relation between the production per unit capacity has been calculated. In case of wind energy it is not possible to use all capacity to its maximum[1], but one could argue that due to technological development this relation should improve through the years.

Table 2 Wind turbines, production related to capacity

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
GWh / MWe	1.14	1.00	0.98	0.96	1.35	1.26	1.52	1.23	1.46	1.43	1.75

Although a general improved can be determined, it is doubtful if all changes were caused by changes in technology. In a number of years the ration decreases, suggesting that other influences also have effect.

1 If used to its maximum 1 MW capacity would generate 8,76 GWh a year.

The concept of wind parks is the general accepted other solution to solve the problem of the visual impact on the landscape. A great number of wind turbines has been build therefore in wind parks of wind farms, as they are also called. The total cumulative capacity of wind parks amounts more than 70% of all installed wind capacity. In table xx the cumulated capacity in June 2000 for the different sizes of parks is presented.

Table 3 Wind park capacities

Capacity wind park	> 10 MW	5 - 10 MW	< 5 MW[1]	Other
Total capacity (MW)	140	81	90	120

Source: Web-site Wind Service Holland, 2000

1 Wind parks with more than 3 turbines but smaller than 5 MW.

In 1996 eight wind parks became in operation, of which one was larger than 5 MWe (in fact the capacity amounted 11,4 MWe). In 1999 five wind parks were established, of which four were larger than 5 MWe. The capacity of individual wind turbines had increased and total installed capacity was almost the same in both years. Therefore the total number of wind turbines in 1999 had decreased (79 to 139 in 1996) and the capacity of the new wind parks was 67% of the total installed capacity in 1999, compared to 62% in 1996.

It can be concluded that scaling-up of individual wind turbines was successful in recent years. The use of wind parks started earlier[123] and seems to have no strong effect on the problems of visual impact, although without the parks the problems could have been even greater.

123 Already at the beginning of the nineties in parliament a motion was accepted for to take measures for reservation of space for large wind parks (TK 1992–1993, 22 606, nr. 9).

Very recent a number of environmental groups presented a study in which for all provinces locations are suggested, that are suitable to install wind turbines on. Because to minimise the visual impact of the turbines, the groups have chosen for clusters of turbines along existing infrastructure and on large industrial areas. The groups explicitly consider wind energy an important renewable energy source and they belief more turbines could be used in the Netherlands, without negative impacts on the landscape and nature. In total they come up with locations with a possible joint capacity of more than four times the existing wind capacity (Stichting Natuur en Milieu, Provinciale Milieufederaties, 2000).

Also off shore wind parks can reduce the visual impact of the wind turbines. Nowadays plans for such parks are drawn,[124] but costs are higher than on shore parks, among other reasons because of the maintenance costs. In 1994 the first pilot installations was built in the IJsselmeer. The wind park consisted of 4 turbines with a joint capacity of 2 MWe and was owned by the utility ENW.[125] In a recent study of STT wind parks at sea are seen as a viable option and are expected to deliver around one third of Dutch electricity generated by renewable sources in 2020. Wind parks located on land are expected to deliver 12% of electricity from renewable sources (Mey, 1999). At sea resistance because of the visual impact seems not to be the obstacle, but here concern for bird-safety and negative visual impact is used as argument.

Recently studies have been conducted in commission of the Novem by a number of companies and institutes to the feasibility of offshore wind energy. A study concerned a 100 MW wind park, what is very large. Among the parties involved were companies from the offshore industry as well wind industry. The plan probably will be realised. Although the park is mend for demonstration, a grant from the governmental CO2-reduction fund will make it probably profitable (Kuik, 1998).

The development and diffusion to offshore turbines has been slow. The first experiments consisted of turbines similar to the land types, that stand in shallow water. Effects of a long preparation period are the accompanying high cost for preparation, the possibility of changes in finance structure or conditions and the risk of installing a wind turbine of technology that has improved during the period. According to Beurskens and Janssen[126] the delays are the reason for the decrease in capacity installed in 1996 and 1997. Mulekom (1999) presents the average preparation period for a number of projects in 1998. The preparation of twelve projects for solitaire turbines lasted 8 to 87 months, an average of 29 months. Three projects for wind parks had preparation periods of 36, 36 and 108 months. Mulekom attributes the long periods to the permit granting and appeal procedures.

Actors

Manufacturing industry

The Dutch manufacturing industry for large wind turbines (>100 kW), in total three companies, held a share of 10% on the world market in 1994 (van Zuylen et al, 1999, pp. 17). In 1996 the two largest Dutch manufacturers had a market share (based on cumulative sold capacity) of respectively 2,4 and 2,2%.[127] Also their position in the Dutch market was strong. This position weakened through the years and Danish manufacturers became dominant in the Dutch market. Of the 1249 installed wind turbines up to February 2000 54% were of Dutch fabricate and in total 41% of the capacity and 34%

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[124] Although as soon as in 1976 a Workgroup Offshore Technology was founded in the Delft University of Technology, that is involved in wind research and education (website Institute for Wind Energy, Delft University of Technology).

[125] European Commission, Directorate-General for Energy, *Wind Energy - the facts, vol. 1, Technology Appendix*, CS-16-98-392-EN-C, 1998

[126] Beurskens, H.J.M., L.G.J. Janssen, Wind energy (in Dutch), in Engelen et al, 1998

[127] European Commission, Directorate-General for Energy, *Wind Energy - the facts, vol. 1, Technology Appendix*, CS-16-98-392-EN-C, 1998

of the production was of Dutch nature. The average wind turbine installed in the Netherlands had a capacity of 343 kW[128], while the Dutch wind turbines hold an average capacity of 257 kW. In general it could be suggested that Dutch industry does not aim at real large-scale wind turbines, but in fact industry is. Lagerwey the Windmaster does sell wind turbines up to 750 - 800 MWe.

Windmaster is a manufacturer involved in wind energy since 1978. Lagerwey, another Dutch company, took over the company in 1998 (website 2000).

Nedwind was established in 1990 as a merger between three smaller companies who had all been involved in wind energy since the early 1980's. In 1999 Nedwind was taken-over by a Danish company and renamed in NEG Micon Holland B.V.

In the capacity range up to 100 kW two Dutch manufactures were active, of which only one still exists. But also Lagerwey has been very successful with turbines up to 80 kW for private operators[129]. The three rotor-blade manufacturers in the Netherlands have (had) a more strong position on the world market (second to Denmark) (van Zuylen et al, 1999). In recent years two of the three have been taken over by other manufactures.

The Danish manufacturing firms have become the most important ones in the Netherlands. In recent years (1999 and 2000) hardly any Dutch manufactured wind turbine has been installed in the Netherlands. In 2000 even eight old Dutch wind turbines have been replaced (website WSH, 2000). The Danish companies managed to do this by firstly lower prices offered. Because they had a larger turnover they benefited economies of scale. Secondly they experienced faster technical progress and increase in turbine capacity. As a last reason is mentioned faster and better maintenance services.

For the first two explanations for foreign supremacy government is to blame according to Wolsink (1996). The choice for large-scale wind turbines was made too early. Government should have created a home market first with small-scale applications of wind turbines. Wolsink is here referring to the national wind industry and not to the diffusion of wind turbines. Furthermore the problem of sufficient suitable sites also obstructed diffusion of wind turbines, preventing the emergence of a home market. This home market is of importance according to him, because when large enough it could provide serial production. One can argue if it is important to have a national wind industry. Wolsink himself explicitly states that the implementation of the Windplan of the distributors could have been achieved also with reliable turbines already available on the international market.

Also Verbong signals the problems of the Dutch wind industry. From the beginning the Dutch industry was not capable of competing internationally. Research had provided in the 80s knowledge, but industry because of lack of finances was not able to implement this knowledge. As a result prices staid too high and purchasers found the turbines too expensive. Furthermore the unreliability was also used as an argument. This reasoning caused a vicious circle in which progress was blocked. Industry did not improve their products and purchasers did not buy the products, preventing the emergence of a market industry needed. Berdowski and Stokx (1994) add to this the specific demands of the distributors (MAP) that caused a change in focus and knowledge[130] of industry. While concentrating on the Dutch market they experienced a disadvantage on the international market, because of the different international specifications for wind turbines.

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[128] The average capacity of the turbines installed per year increased from 377 (1996), to 492 (1997, 649 (1998) and 669 MWe (1999).

[129] As in later years the market demand changes to larger capacities, Lagerwey experienced problems because they had not anticipated in time (Vries, E. de, Barsten in trotse nationale windindustrie, *Energietechniek*, 5 - 77, 1999, pp. 254 - 258)

[130] And knowledge is very important for manufacturers, because as for to produce wind turbines knowledge is a necessity, for production no special machinery or conditions are required.

In conclusion it can be stated that the home market for Dutch manufacturers has staid small and entry of the foreign market did not go well. So it was not possible to benefit of economies of scale and prices did not fall.

Although ownership has changed and this has led to less Dutch manufacturers, this not necessarily has to be considered a hindrance for the diffusion of wind technology. All former Dutch companies taken-over are still active on the Dutch market. And also foreign manufacturers do use representatives to deal with the Dutch market.

At international level competition between manufacturers is strong. This has as effect that profit margins are low and that industry without public support could not generate sufficient profit to autonomously sustain a major R&D program.

Wind energy producers

The pioneers of the seventies were not from the production sector. The first investors in wind energy were private organisations or co-operatives. In later years utility companies become more important. First the SEP is involved in a demonstration wind park, as an effect of the large-scale aim of NOW 2 (1982). The production sector did not approve wind energy, because they hold a number of problems of technical nature against it: The inherent unreliability of wind energy; The lack of storage capacity; and The problems of integration of wind turbines into the nation grid. Also “According to government these limitation meant that wind power could never substitute a substantial part of the vase generation capacity.” (Verbong 1999, pp. 148). After the Sexbierum wind park, central producers never have been involved in wind energy again.

The MAP of the distributors of 1990 was the second attempt for large-scale wind applications. The involvement of the distributors is successful in terms of ownership, now the distributors own more than half of the wind capacity. The MAP came as a reaction on the task set in the NEP and Energy Saving Act of 1990 for the electricity sector. The 250 MW Windplan, set up as a consequence of the MAP by eight distributors, experienced great hindrances, of which the spatial integration was the major one. According to Wolsink (1996, pp. 1084) the distributors lacked experience with small-scale physical planning and local politics. Besides this lack of experience, the distributors demanded specific turbine characteristics (especially concerning scale) that were uncommon, so manufacturers could not meet these demands. Because of the national policy goal to stimulate Dutch wind turbine industry distributors favoured national firms. Dutch industry therefore concentrated on the Dutch market, with its own characteristic demands. When the distributors failed to implement the Windplan and ended it in 1993, they left “… manufacturers with designs ill-suited for the international market place.” (Gipe, in Wolsink, 1996, pp.1085).

Furthermore the distributors, after the split up of the sector in 1989 legally able to operate generation capacity below 25 MW, considered wind power a possibility to generate electricity of their own. By means of a by government approved levy on all electricity they managed to finance a part of the capacity. In later years the concept of green electricity stimulated the installation of wind turbines.[131]

It lasted until the mid 90s for wind energy diffusion took place on a larger scale. The actors involved were energy distributors, private project developers, agriculturists and co-operatives. But of all actors involved the distributors were the most important through the years in terms of ownership. At the end of the nineties about 50% of installed capacity was owned by the utilities. (WSH, 2000) The role of the co-operatives has become very small, hardly any new wind turbines have been installed by them (Mulekom, 1999, pp. 13).

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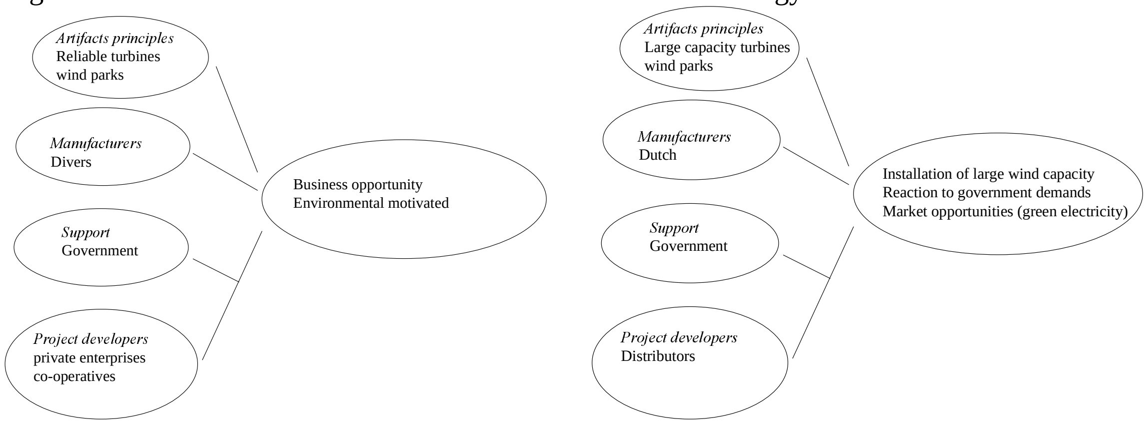
[131] Although for green electricity it is not necessary that the distributors owned the wind turbine, the additional income could be used for investments in wind power.

Figure 3 Actors involved in diffusion of wind energy



Research organisations

The expertise on wind energy has been concentrated[132] at the *Delft University of Technology* (DUT) and Netherlands Energy Research Foundation (ECN). Both organisations work together and share experiment facilities that can be used by manufacturers of wind turbines to determine performances. The content of the research program follows after deliberation with the Novem for the NRW-plan.

The DUT has been involved in wind energy research and education since 1976. In the first period the research mainly concerned wind turbine rotor aerodynamics at the Faculty of Aerospace Engineering. In 1976 also the Workgroup Offshore Technology (WOT) was founded to ensure co-operation in this field. In 1984 a contract research organisation, the Institute for Wind Energy (IvW) was founded. Both groups work together in recent years in the field of offshore wind energy. Research at the DUT is in general of technological nature.
(Source: http://www.ct.tudelft.nl/windenergy/ivwinfo.htm, 2000)

ECN has been involved in wind energy since the organisation BEOP was established by government at ECN to co-ordinate and manage the NOW 1 program. In later years the wind energy group involves one of the six priority areas in ECN. Research includes technical, economical, environmental and institutional elements as well as system integration aspects.
(Source: http://www.ecn.nl/unit_de/wind/main.html, 2000)

According to Kuik (1998) wind energy is no profession, but a field of application in which a number of professions meet. This makes it hard to train students, because only when they master the professions it is possible to integrate the professions.

Intermediaries

In the *Dutch Wind Energy Association* (Newin) since 1983 persons and organisation, professionally involved in the introduction of wind energy in the Netherlands are associated. The aim of the organisation is to promote wind energy by knowledge transfer and consultation with other groups involved.

Wind Services Holland (WSH), established in 1982, is involved in the application of wind energy. Since 1988 it provides calculations on the yield of wind turbines. Furthermore it provides information over all aspects concerning application of wind energy in the Netherlands.

[132] See for instance Hilten, 1996, pp. 63. But there are other organisations active in research, like KEMA.

Novem, and in earlier time its precursors, has been involved in executing a number of governmental plans for supporting R&D and implementation of wind turbines. It holds a crucial position in both formulating and executing programs.

Major hindrances for diffusion

Spatial integration

The demand for wind electricity is large enough to justify instalment of wind turbines. The major obstacle seems to be the spatial integration of the wind turbines. There are two main mechanisms that can be believed to be at work: there is competition with other spatial functions, and decision making is faced with opposition of local residents and environmental groups.

The first mechanism does not seem too important, because other authors or respondents do not mention it. The argument of opposition is on the other hand mentioned very often. Opposition can work by different ways, by actors that oppose and by the possibility to oppose.

Actors opposing wind energy

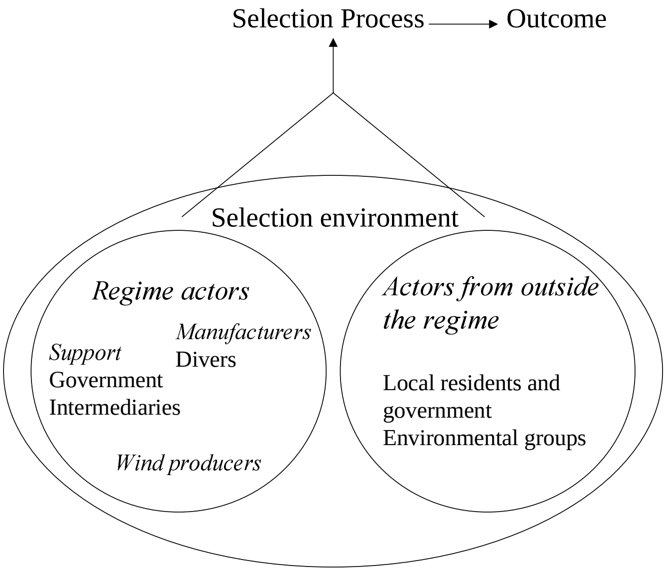
When actors are to 'blame', it is considered that the benefits and necessity of wind energy is not clear to actors. From the lack of percepted benefits the local costs are decisive. On a local level therefore the support is limited and wind energy projects are faced with long lasting and complex legal procedures. (And as an effect of the sometimes very long period between start an implementation technological older techniques become implemented) (Project Agency Sustainable Energy, PDE, 2000).

Until 1991 the national government held the idea that finding sites for wind turbines would not be a problem at all. It was expected that local authorities, which decide on building permits etc, would co-operate in achieving the wind energy goals (Wolsink, 1996, pp. 1081). The public opinion at that time was also largely positive about wind energy. As it turned out the national and local policy goals did not meet. Because local authorities do decide on zoning schemes[133], the national goals of installing wind turbines could not be achieved. The reason local municipalities did not co-operate to meet the national goals is supposed to be the NIMBY syndrome. Although the public at large is in favour of wind energy, instalment of turbines in their own neighbourhood is problematic. When it comes to wind energy, the negative effect of the visual impact outweighs the positive effects on energy generation. But it is not necessary that a majority of locals opposes a wind energy project. As far as NIMBY is concerned in the Netherlands an individual can start legal procedures in order to prevent a change in the zoning scheme. Although the general public opinion can be positive this is clearly not sufficient to prevent opposition in case of a new project.

But this not seems to be the whole answer. For certain groups the installation of wind turbines has a negative visual impact on the landscape, even when it is not close to their residence. These groups therefore also oppose instalment of turbines in rural areas, etc. Other effects are also taken into account, such as the scenic value of the landscape the turbines are planned in, the noise, effects on birds, etc. The word 'group' here used is also in place, because the opposing actors often consist of national organised environmental groups. This opposition could for these arguments be called more than NIMBYism.

[133] For the spatial planning municipalities draw zoning schemes, in which areas are reserved for specific functions or activities. A building permit is granted when the object fits in the approved zoning scheme.

Figure 4 Selection process for wind



It is here that in recent year a change has occurred. In 1996 Wolsink argued that "The belief of wind power as a clean renewable energy source is only of secondary importance when people form their attitude towards wind energy, and it appears to be almost irrelevant when they are considering their behaviour concerning a proposed wind project in their region." (Wolsink, 1996, pp. 1087). In the year 2000 a number of environmental groups that has been critical about wind energy projects through the years, came up with a plan to deal with the siting problems. The reasoning to make a plan like that lies in their viewpoints against renewable energy, of what they are in favour. In their plan they give guidelines to plan wind turbines in the landscape with minimal impact on the landscape and nature and they do suggest for all provinces locations for wind turbines. They conclude that there are enough sites for which no resistance of third parties will emerge and on which more than four times the present wind capacity can be installed (Stichting Natuur en Milieu, Provinciale Milieufederaties, 2000).

This new position of the environmental groups can be considered to be in line with recommendations in the field. A trade off between all costs and benefits has to be made. When local interests not prevail at all times, a just deliberation can be made. But how can you make people take more than local interests in consideration. According to the Ministry of EA by educate them. Therefore they suggest to support research on environmental effects of wind turbines.

National government around 1991 acknowledged the position of municipalities and the problem of finding sites for wind energy. An agreement with the seven windiest provinces on siting of wind turbines was concluded in 1991. This agreement though did not have much effect, as the provinces did not have authority in the planning process. In case of spatial planning, provinces conclude regional plans, but these plans only indicate in a more global manner the spatial function of plan areas. Because only the provinces were involved in this agreement, translation of regional district plans into municipal zoning plans was not successful at all.

Possibility to oppose

Already described above are the positions of the different governmental bodies. As it turned out to be the sustainable energy goals have not been well co-ordinated[134] by the central government. Provinces and local municipalities do not feel responsibility for these goals and the national policy does not have consequences for other public authorities. And because wind energy is for those authorities political of no importance, most governmental bodies do not have an active policy for wind energy or are even

[134] Or made mandatory.

negative about wind energy. (As measures the Ministry of EA has suggested the establishing of a National Wind Energy Bureau, as an independent reference centre and the establishment of Regional Wind Energy Consultative Bodies, to promote consultation between all actors involved.)

<u>The position of the distributors</u>
The position of the distributors for wind energy is questioned (PDE, 2000). Electricity distributors did not only sell electricity, but were also operators of the distribution net. In that capacity they are able to set the rules for to connect a wind turbine to the grid. In almost all cases, with and without a grid close by to connect to, all cost for the infrastructure to connect are charged to the wind turbine owner. This makes connection more expensive than necessary, but because of the monopoly position of the distributors wind energy producers do not have a choice. A second observation of the PDE concerns the own activities with wind turbines of the distributors. These activities (project developing) make them competitors of the private wind project developers.

Furthermore remuneration tariffs for wind energy have been very low in the Netherlands. These tariffs therefore did not give an incentive to private operators to produce as much as possible. Through the years no tariff regulation for renewables has existed. The electricity sector was allowed to determine the tariffs by itself and because private operators had no way of selling the electricity to a third party and there was no competition between distributors, they could set the tariffs low.

The electricity sector was not willing to pay higher prices for wind energy because they considered wind capacity as unreliable. No capacity compensation therefore was in order according to the sector. It is even stated that for all installed wind capacity a same amount of conventional back up is necessary, what results in high cost for the electricity sector as the responsible for continuous electricity delivery. As a result the avoided fuel costs for (conventional) electricity generation were starting point for the tariffs. Compared to other countries the level of Dutch tariffs catches the eye. In for instance Germany in the remuneration tariffs compensation for avoidance of high external costs[135] are included.

In recent years, due to the concept of ‘green’ electricity, some distributors have risen the remuneration tariffs. Additionally in recent years the price difference between wind generated electricity and conventional generation has decreased, as result of the REB. Electricity sold to households generated by wind nowadays can compete with fossil generation because the electricity sold is free from REB.

R&D programs for wind energy

The first stimulus for R&D on wind was the 1976 national research and development program on wind energy (NOW 1). The program co-ordination and management was assigned to the Bureau Energy Research Projects (BEOP), established especially for this purpose. The budget of the program amounted 9 million ECU up to 1981. The programs aim was to determine the possible contribution of wind energy to energy supply. This included inventory of options, fundamental research and demonstration[136] of turbine concepts (Verbong, 2000). The results, although limited, were seen as positive (Wolsink, 1996). In 1982 the second research program was launched, NOW 2, what aimed at large-scale applications (although already in the first program large-scale applications, wind parks, were the dominant view[137]). This led to the demonstration wind park operated by the SEP and subsidies for development of large-scale turbines by industry. This latter aspect was a consequence of the wish of government to involve industry. As effect the program stressed more the creation of the market than research (as the first program did).

From 1986 until 1990 the Integral Programme Wind Energy (IPW) was in effect. This programme aimed at cost reduction of wind energy, by providing subsidies for installed wind capacity.

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135 The external cost for non-renewable generation concern mainly the environmental impact of burning fossils.
136 For the prototypes demonstration there was collaboration with Fokker Aircraft and the National Aerospace Laboratory (NLR).
137 Verbong, 1999, pp. 142

In 1990 again a new research program, the Use of Wind Energy in the Netherlands (TWIN-1) was started by the government. The Novem executed the program. The available budget for the period 1991 - 1995 was about Dfl. 10 million a year. According to Novem the program gave a considerable impulse to the growth in capacity installed, but did not led to an autonomous market for wind energy. After the ending of the program it was therefore followed by Twin-2.

"Research under the TWIN-1 program was increasingly controlled by industry. This led to more intensive co-operation between industry and scientific organisations." (van Zuylen et al. 1999, pp. 18).

The follow up program in 1996 (TWIN-2) for the period 1996 - 2000 had a (n estimated) budget of Dfl. 15 million a year (van Zuylen et al, 1999, pp.18). The program holds a strategy to create the conditions with which the governmental targets can be met (100 MW installed a year). In the program four areas for support are distinguished[138,] this is the installation and the technology, both before and after the year 2000.

In the area installation up to 2000 as especially important is considered by Novem co-operation between all parties involved to create the right conditions for installation of wind turbines. As conditions are mentioned sufficient sites, new implementation concepts, sufficient support and funding.

For the installation after the year 2000 the activities in the program will deal with the possible inland sites (until now for a great part ignored), possible co-operation with large landowners, possible use of semi-ofshore sites, possible import of wind energy and research and demonstration of offshore wind energy.

The third area contains the technology up to 2000. The aim is to improve the price performance relation with 30% in the year 2000 compared to 1995. This improvement is supposed to be reached by application of new technical developments and by increasing the production volume.

For the technology after 2000 a National R&D Plan for Wind Energy (NRW) is used. The TWIN-2 program supports this research by development of new concepts, design tools and engineering methods.

In 1996 also a R&D support program started, the National R&D Plan for Wind Energy (NRW). The content of this plan was built on parts of the research programs of ECN, TU Delft and the Novem, what makes clear what parties were participating in this program. The aim of the program is to adjust the R&D activities of the different participants in the program in order to fine-tune R&D programmes for wind energy and strengthen the positions of the whole wind energy sector. This National R&D plan wind energy aims at a joint long-term development strategy and co-ordination with the Dutch wind engineering industry, to develop knowledge. In later years the program was renamed in Dutch R&D Strategy Wind energy, abbreviated as also NRW. For to establish the bi-yearly plans an advisory board is used, the industrial Platform NRW, that consists of the knowledge users.

In the strategy for 1999 - 2003 it is acknowledged that also system integration is of importance. As motivation the larger application of wind energy is mentioned (ECN et al., 1998b).

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[138] Novem, *The multi-annual programme TWIN-2*, Novem, Sittard / Utrecht, 1996