

# Explaining the rapid diffusion of Dutch cogeneration by innovation system functioning

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## Abstract

In this paper, we apply the functions of innovation systems theory to explain the successful diffusion of cogeneration technology in The Netherlands. We show that the technological innovation system for cogeneration functioned very well and that this explains for a major part the successful diffusion. We also show that the innovation system was positively influenced by actions of the Dutch government. Government actions were aligned to the needs of the other parties in the innovation system. Finally, we show that part of the successful diffusion can be attributed to changes in the institutional environment that were not intended to stimulate cogeneration. © 2007 Elsevier Ltd. All rights reserved.

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## 1. Introduction

An important aim of climate policy is to stimulate the development, application, and diffusion of technologies that lead to carbon emission reduction. Earlier work published in *Energy Policy* emphasizes the difficulty to change our current ways of producing and using energy towards a sustainable practice. Unruh for example, has labeled this as carbon lock-in (Unruh, 2000). Important reasons for this carbon lock-in are that fossil-based technologies used at present, have gained cost-advantages over the years and still receive subsidies (Norberg-Bohm, 1999). Second, the institutional arrangements have co-evolved with these technologies and, therefore, often choose to support existing technologies instead of emerging technologies (Unruh, 2000). Third, in highly regulated markets such as the energy market, market imperfections are likely to occur.

To overcome this situation of carbon lock-in, it is important to create insight into the inducement and blocking mechanisms that influence the emergence of

low-carbon technologies. There has been an increasing recognition in the science and technology policy community that technological change and development is best understood as the outcome of ‘innovation systems’ (Sagar and Holdren, 2002). The central idea behind the innovation system approach is that innovation and diffusion of technology are *both* an individual and a collective act. The innovation system approach encompasses individual firm dynamics, as well as institutional arrangements in which individual firms have to operate. Determinants of technological change are not only to be found within the individual firm but also within the innovation system. An innovation system can be defined as the institutions and economic structures that affect the rate and direction of technological change in society (Edquist and Johnson, 1997).

Recently, several scholars have taken up the challenge to analyze under what conditions emerging technologies have a high chance of becoming successfully embedded in the existing system (e.g., Jacobsson and Johnson, 2000; Johnson, 2001; Negro et al., 2007; Hekkert et al., 2007). They have studied what the main functional requirements are of the innovation system that need to be fulfilled in order to lead to successful development, application, and

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diffusion of new technologies. Most of these studies apply the ‘functions of innovation systems’ approach to emerging technological fields. Since by definition diffusion is low for emerging technologies, it is problematic to test whether a good fulfillment of these functions of innovation systems indeed leads to successful diffusion. Therefore, to bring this approach a step further, it is important to analyze the historical development of successfully diffused technologies.

In this paper, we will apply this approach to explain the rapid and successful diffusion of cogeneration technology in the Netherlands. In this paper, we aim to analyze how the functioning of the cogeneration innovation system influenced the diffusion of decentralized cogeneration technology in the Netherlands. Furthermore, we will be giving special attention to the role of the government, influencing the functioning of the innovation system.

## 2. Innovation system functioning

Since well-performing innovation systems are crucial for the possible success of innovations, policy should be focusing on strengthening innovation system performance. For the diffusion of cogeneration technology, only a limited (technology specific) part of a national innovation system is of interest, which we will define as the Dutch cogeneration innovation system: all actors and institutional structures that affect the rate of diffusion of cogeneration technology.

Just to show a few examples, the cogeneration innovation system consists of producers and users of cogeneration technology, government bodies that formulate energy policies, but also the subsidy schemes and tax regulations related to cogeneration are part of it.

For well-performing innovations systems, a number of requirements or functions need to be accomplished. In (Hekkert et al., 2007), seven functions are defined, based on a review of several recent publications. These functions are crucial for well-performing innovation systems.

### 2.1. F1: entrepreneurial activities

An innovation system without entrepreneurs is no innovation system. Entrepreneurs are vital for a well-functioning innovation system. Entrepreneurship is often viewed as a function, which involves the exploitation of opportunities, which exist within a market. Entrepreneurs are persons that are considered to bear risk while pursuing business opportunities; they often are associated with creative and innovative actions. Thus, the role of the entrepreneur is to turn the potential of new knowledge development, networks, and markets into concrete actions in order to generate and take advantage of business opportunities. In the case of cogeneration in the Netherlands we expect most entrepreneurial activities to be decisions of industries to adopt cogeneration technology and integrate it into their production process.

### 2.2. F2: knowledge development

Mechanisms of learning are at the core of innovation processes. For instance, according to Lundvall, “the most fundamental resource in modern economy is knowledge and, accordingly, the most important process is learning” (Lundvall, 1992). Therefore, R&D and knowledge development are prerequisites of the innovation system. This function encompasses ‘learning by searching’ and ‘learning by doing’. Knowledge development not only includes the development of technological knowledge; other important aspects are knowledge of innovative financing schemes, user experiences, and insights into the bottlenecks that limit diffusion.

### 2.3. F3: knowledge diffusion through networks

According to Carlsson et al. (2002), the essential function of networks is the exchange of information. This is important in a strict R&D setting but also in technology diffusion settings. When the development of individual knowledge (as mentioned above) is diffused throughout the network, learning at system level takes place, which greatly enhances technology development and diffusion.

### 2.4. F4: guidance of the search

Since resources are limited per definition, it is important that, when various technological options exist, specific foci are chosen for further investments. Without this selection there will be insufficient resources left for the individual options. This function can be fulfilled by a variety of system components such as industry, government and/or market. The process of building positive expectations of a new technology is a powerful way to guide the search process. High expectations of new developments will attract entrepreneurs and persuade early adopters to enter into the new market. Whereas knowledge development (function 2) can be regarded as the creation of technological variety, this function represents the process of selection.

Another aspect of this guidance function is that it helps to broaden the mental map of ‘rationally bound’ actors. Sometimes, the adoption of certain technologies is not even considered, for instance when the potential adopter is not aware that the technology exists and that it might be beneficial. Studies that create insight in the market potential of new technologies may be beneficial in such a case.

### 2.5. F5: market formation

Potential markets for new technology are quite often present, yet new technologies often have difficulty competing with embedded technologies and conquering these potential markets. The reason is that new technologies are often badly adapted to many of the ultimate uses to which

they will eventually be put. Therefore, they often offer only very small advantages over existing techniques, perhaps even none whatsoever (Rosenberg, 1976). Thus, new technologies need to be supported as they conquer potential markets. One way of doing this is by creating a protected space for new technologies: the formation of temporary niche markets for specific applications of a technology (Schot et al., 1994). In such an environment, actors can learn about the new technology (F1 and F2) and expectations can be developed (F3). Another possibility is to create a (temporary) competitive advantage by favorable tax regimes (e.g., the Dutch experience with reducing energy taxes for renewable energy) or minimal consumption quotes (e.g., the German feed-in law for renewable energy).

### 2.6. F6: resources mobilization

Resources—both financial and human capital—are necessary as basic input for a well-functioning innovation system. Both R&D and the construction of production facilities require financial resources, either from internal or external funds, e.g., government subsidies and venture capital. In terms of human capital, one could think of well-educated and knowledgeable professionals in all parts of the innovation system.

### 2.7. F7: creation of legitimacy/counteract resistance to change

In order to develop well, a new technology has to become part of an incumbent regime, or it even has to overthrow that regime. Parties with vested interests will often oppose to this force of ‘creative destruction’. In that case, advocacy coalitions can function as a catalyst; they put a new technology on the agenda (F3), lobby for resources and favorable tax regimes (F5 and F6) and by doing so create legitimacy for a new technological trajectory (Sabatier, 1988). If successful, advocacy coalitions will grow in size and influence and they may become powerful enough to brisk up the spirit of creative destruction.

Functions influence each other. The fulfillment of a certain function will quite likely influence the fulfillment of other functions. Therefore, we expect a non-linear, causal model with multiple interactions between functions that will positively affect the performance of the system. The fact that functions interact with and influence each other may be considered a necessity. Jacobsson and Bergek (2004) have described the mechanisms of change processes of innovation systems (Jacobsson and Bergek, 2004). According to them, the function fulfillment could lead to virtuous cycles of processes of change that strengthen each other and lead to the build-up of momentum to create a process of creative destruction within the incumbent system. Therefore, our empirical research focuses on creating insight into the way the process of momentum

building and destruction takes place. This should lead to important insights into the way to influence the innovation direction in nations and sectors. Since we expect to find virtuous cycles that influence system dynamics, it is particularly valuable to evaluate a success case such as the diffusion of CHP in the Netherlands.

Our starting point is the assumption that successful development and diffusion of new technologies can be explained by well-functioning innovation systems. However, what exactly are the explanatory factors that determine whether or not an innovation system functions well? This is a key question for policy makers, for they are only marginally able to directly influence the functioning of innovation systems. In this paper, we use the starting point that it is the institutional set-up that has a large influence on system functioning. For example, changing the institutional structure by setting very ambitious carbon emission targets, backed up by the right financial incentives, is likely to trigger quite a number of activities in terms of development and diffusion of low-carbon technologies. To explain the success of cogeneration in the Netherlands, we will, therefore, not only analyze how the innovation system functioned over the last decades, but we will also focus on the changes in institutional structure that influenced this system functioning.

## 3. Diffusion of decentralized cogeneration in the Netherlands

Fig. 1 shows the development of electricity production by decentralized cogeneration in the Netherlands in the period 1982–2004. At the end of the 1990s, almost 30% of the total Dutch electricity production came from decentralized cogeneration, compared to 10% in the early 1980s.

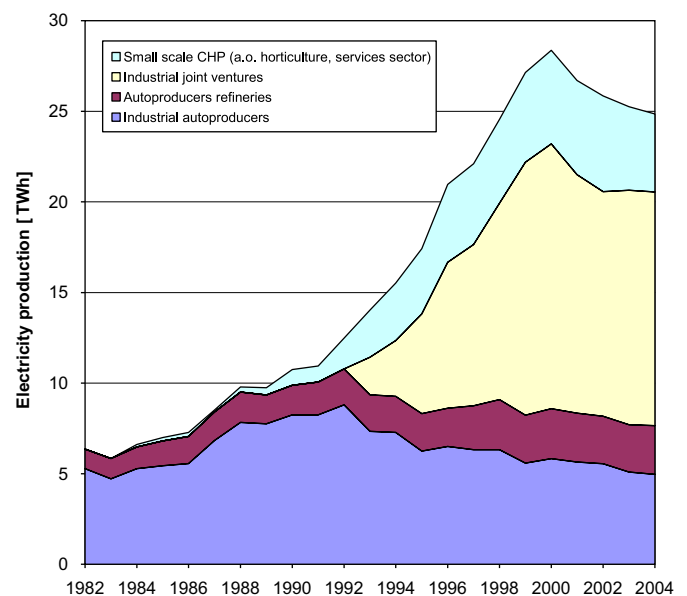


Fig. 1. Electricity production by decentralized cogeneration 1982–2004 excluding district heating (Source: CBS, Statistics Netherlands).

In absolute terms, the electricity production by decentralized cogeneration increased with more than a factor four.

In the early 1980s, decentralized cogeneration accounted for 21% of the total heat demand of the industry, refineries, and other end-users such as the horticulture sector. At the end of the 1990s, a similar share was reached, although, in absolute terms, the heat production by decentralized cogeneration was somewhat higher than in 1982, see Fig. 2.

Based on these figures, we can draw the preliminary conclusion that the success of decentralized cogeneration cannot be explained away as the conquest of the Dutch heat market, since on a cumulative base, only one fifth of the relevant heat market was and is served by cogenerated heat. The reason that the development of Dutch cogeneration is generally recognized as a success story is purely based on the electricity part. In this paper, we will show how a well-functioning innovation system led to success. As can be seen in the figures above, the success story of cogeneration came to an abrupt end after 2000: both its electricity and heat production decreased. This decline will also be explained in terms of innovation system functioning.

### 3.1. The cogeneration innovation system wakes up (1970–82)

At the end of the 1970s, cogeneration was already a well-known technology to large companies such as Shell, DOW Chemicals, DSM and companies in the paper and food industries. They had their own internal market for both heat and electricity (F5), large enough to make cogeneration profitable. Moreover, these companies had the knowl-

edge (F2) to integrate the technology into the production process, they had the capital to invest (F6) and, quite important as well, they had the need for an autonomous position. They wanted to be independent—at least to some extent—from the power producers (F4) because of the increasing Dutch electricity prices (Harmsen, 2000): Between 1974 and 1982, the electricity price had doubled, which made the economics of cogeneration more attractive. Steam expansion turbines were the dominant technology. Knowledge about these turbines often came from chief engineers who were familiar with similar technology used in ocean-going trade. The turbines were designed to serve the company's electricity demand to minimize export to the grid and so minimize the interaction with the power producers.

Apart from the activities of the large companies, there was little movement in the cogeneration innovation system. Small companies lacked the knowledge and resources to even consider investing. In terms of innovation system functioning, knowledge diffusion (F3) was clearly not functioning well yet. The Dutch government mentioned cogeneration in the White Paper on Energy (Ministry of Economic Affairs, 1974), but did not give it a prominent role (F4). It was only at the end of the 1970s that the Dutch government recognized the potential of cogeneration for saving energy and energy costs. Based on the advice of the Dutch Energy Council (AER, 1978), the government installed a Commission on Cogeneration in the Industry, mid 1979. This created both legitimacy for the technology (F7) and focus, namely on the industry (F4). Members of this Commission were representatives of the industry, power producers, Gasunie (the Dutch gas company), the Ministry of Economic Affairs, and NEOM (now SenterNovem). NEOM, the executive body of the Ministry in the field of energy, was founded in the mid 1970s to serve as a bridge between technology suppliers and users (Verbong, 2004). It was NEOM asking the Dutch Industrial Power Users Association (Krachtwerktuigen, now VEMW) to study the potential of CHP in the Dutch industry (F2). This study was performed in 1978/79 and showed an additional potential of 2000 MW<sub>e</sub> in the year 2000, compared to the 1100 MW<sub>e</sub> installed in 1980 (Krachtwerktuigen, 1979). The results of the study were adopted by the Commission on Cogeneration in the Industry. In its report to the Minister of Economic Affairs, the Commission stressed the necessity to tackle the barriers, which could hamper further diffusion of cogeneration (Commissie Warmtekrachtkoppeling in de industrie (CWK), 1980). One of the important recommendations was to incorporate decentralized cogeneration in the capacity planning of the central power producers. According to the Commission, natural gas should be made available for use in cogeneration, at least in the short term (i.e. till 1985). The Commission emphasized that, because of diversification policy, coal was the preferred cogeneration fuel in the long term when new innovative technologies, developed by Dutch (research) institutes such as ECN, TNO and Shell,

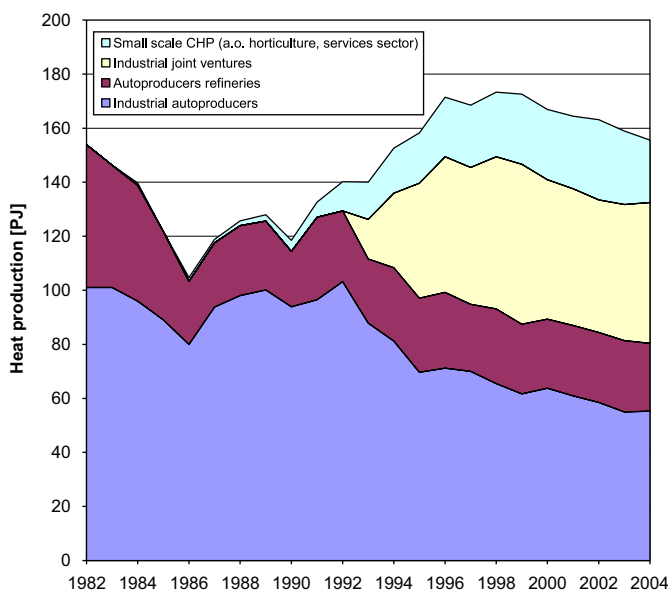


Fig. 2. Heat production by decentralized cogeneration in the period 1982–2004 excluding district heating (Source: CBS, Statistics Netherlands).



and to be built by the Dutch industry (Verbong, 2004), would be available in the mid-1980s.

Already in 1974, the Dutch government had adopted this diversification policy (Ministry of Economic Affairs, 1974). Ideally, the mix for electricity production should contain one third of natural gas/oil (interchangeable), one third of coal, and one third of nuclear energy. Along with the diversification policy, the government adopted a restricted gas policy. This diversification policy differed from the earlier rapid-exploitation-of-gas policy that had started in the 1950s, when vast amounts of natural gas resources were discovered in the northern part of the Netherlands. At that time, it was generally understood that nuclear energy would be the dominating energy source of the future (Ministry of Economic Affairs, 1957). Therefore, the Dutch government adopted a policy of rapid exploitation of the gas reserves (Gasunie, 1973). The idea was simple: to sell the gas before it became worthless. To allow easy use of the gas, a dense distribution grid was established which finally reached almost every Dutch end-user—households, services sector, and industries. Already before the oil crisis of 1973, the government started to recognize that nuclear energy would not be as promising as expected and hoped for. Public opposition rose and nuclear energy became the main target of environmentalists. Even more important, projected growth figures of energy demand were adjusted downwards, time after time, as a result of two global energy crises that prominently put energy conservation (to save money) on the public agenda. Thus, in 1974, the Dutch government left the policy of rapid exploitation (de Jong, 2004). Gas supply to households was given priority above the use of natural gas as industrial feedstock and fuel for power and heat production, including natural gas-fired cogeneration (Ministry of Economic Affairs, 1974).

In 1975, however, 86% of the electricity production was based on natural gas (source: IEA). Production practice (no priority to gas supply for electricity production) and policy intentions (diversification policy) could not have been more different. Therefore, the government adopted an “away from gas” policy, which was formalized in the Power Plant Fuel Use Act of 1980 (SEP, 1981).

In 1981, the Minister of Economic Affairs responded to the work of the Commission on Cogeneration in the Industry in a letter sent to the Dutch Parliament (Ministry of Economic Affairs, 1981). In this letter, the Minister labeled cogeneration as one of the most important measures (i) to reduce energy use in the industry, (ii) to reduce energy costs, and (iii) to create possibilities for the Dutch equipment industry to supply cogeneration components (F4, F7). Although the Minister emphasized that the future use of coal in cogeneration would be necessary from the perspective of diversification policy (F4), he permitted the use of natural gas in cogeneration (F6). From today’s perspective, the term ‘permitted’ might sound somewhat strange to the reader, but one should bear in mind that in those days natural gas was not a free commodity in the Netherlands as it is today. Allowing industries to use

(more) natural gas in cogeneration schemes shows the rising momentum of the technology, especially when taking into account the “away from gas” policy (F4).

Soon after the Minister’s letter had been sent to Parliament, NEOM published a report in which an evaluation was made of the prospects of cogeneration in the industry. In the report, a number of barriers for further cogeneration diffusion were identified (NEOM, 1981):

- Limited capital access and high interest rates (negative fulfillment of F6).
- Uncertainty with respect to compensation for grid export (fuel cost component and capacity component) (Negative F5).
- Hampering cooperation between industries and distribution companies:
  - Possible conflicts between regional power producers and municipal power distributors (Negative F3).
  - Different subsidy regimes between industries and distribution companies (Negative F6).
- Uncertainty with respect to the electricity price because of uncertainty with respect to fuel use for central power production (Negative F5).
- Regulatory issues with respect to re-supply of electricity from one company to another (Negative F5).
- (Too) stringent local emission norms for natural gas-fired gas turbines ( $\text{NO}_x$ ) and coal-fired cogeneration ( $\text{NO}_x$ ,  $\text{SO}_2$  and dust) (Negative F5).

NEOM also observed that the cogeneration growth was behind schedule, as earlier anticipated by the Commission on Cogeneration in the Industry. Moreover, at the same time, the decision was made not to build a coal-fired demonstration plant. NEOM, therefore, advised the Ministry of Economic Affairs to reinstall the Commission on Cogeneration in the Industry.

In June 1982, the Commission published its second report, noticing the need for an advisory body that would facilitate and financially support feasibility studies for (mostly smaller) companies that lacked the in-house expertise (F2).

An important recommendation of the Commission was to reserve natural gas for use in cogeneration, also after 1985 (till 1990), because of the delayed development of innovative coal technologies (Commissie Warmtekrachtkoppeling in de industrie (CWK), 1982). The Ministry of Economic Affairs adopted this recommendation. In 1983, it even decided to remove all restrictions (F6) on the use of natural gas in cogeneration from 1984 onward (Ministry of Economic Affairs, 1987).

Whereas the ‘fuel focus’ (F4) seemed to shift to natural gas-fired cogeneration, the ‘user focus’ (F4) was no longer merely reserved for the industry, as the Commission mentioned the considerable potential for decentralized cogeneration in other sectors (CWK, 1982). The shift of ‘fuel focus’ was accentuated in 1982, when the Dutch government decided to leave its “away from gas” policy

because of budgetary reasons (tax revenues from natural gas). At the same time, coal research budgets were cut (Verbong, 2004). National industry policy became limited after the bankruptcy of a large Dutch company in 1983 and increased EU regulation somewhat later (Verbong, 2004). The bankruptcy also put an end to the founding of a Dutch gas turbine manufacturer (Blok, 1991). Almost unnoticed, the main driver for further cogeneration diffusion became the potential for energy savings (F4). The cogeneration innovation system slowly got ready for further expansion.

To summarize: the awakening of the cogeneration innovation system can be characterized by an important role of the government. First, it analyzed the flaws in the cogeneration innovation system and second, it performed several innovation system functions, where most effort was put in ‘guidance of the search’ and ‘creation of legitimacy’. The removal of restrictions on the use of natural gas proved to be an important structural change that became critical for the success of cogeneration in later periods.

### 3.2. The road to success (1982–87)

With the foundation of a National Investment Bank in 1982 (CWK, 1982), the first barrier identified by NEOM (limited capital access and high interest rates) seemed to be tackled (F6). Projects that—during their lifetime—would save a minimum of 1 million m<sup>3</sup> of natural gas (F4) could get a loan against favorable interest rates to finance their projects. In 1987, however, an evaluation by NEOM showed that realized projects had hardly made use of the financing possibilities (Commissie Warmtekrachtkoppeling in de industrie (CWK), 1987).

It was also in 1982 that the investment subsidy WIR-ET<sup>1</sup> was increased (F6). After its evaluation in 1987, it turned out that this subsidy had been decisive in the realization of projects (CWK, 1987). In the food industry, the paper industry, and the chemical industry several new projects were started (Blok, 1991) (F1). Much of the knowledge necessary in these projects came from Gasunie who had a commercial interest in gas-fired cogeneration technology since it would increase the volume of natural gas sales. Approximately, 90 feasibility studies were carried out annually (both industry and district heating) and in the period 1984–87, the government spent €1.1 million to subsidize these studies (CWK, 1987) (F2, F6), that resulted in approximately 30 new industrial cogeneration projects (F1). Exemplary for increased knowledge diffusion (F3) was that in the food and drug industry, specific designs of cogeneration schemes were copied by several other companies (Blok 1991) (F3). In this period also the committee ‘cogeneration in industry’ was active. This was an industry delegation that lobbied for better circumstances for cogeneration in industry (F7). In this case, we observe a start in positive feedback between innovation system functions.

Indirectly, another policy instrument showed that cogeneration had conquered its place on the political agenda. At the time, Dutch electricity prices were far higher than those of neighboring countries. Therefore, the competitive position of the Dutch industry had become weak. To lower the burden of the industry, the government had decided to lower the electricity prices of large end-users. By doing so, the profitability of cogeneration projects was put under pressure, since this was mainly based on high electricity prices. The government recognized this situation and compensated the industrial autoproducers on the same base as the large end-users without cogeneration (F5, F6) (CWK, 1987).

In 1987, it was quite clear to the Ministry of Economic Affairs how to speed up further diffusion of cogeneration. The Ministry of Economic Affairs recognized that investments in cogeneration were custom-made (Ministry of Economic Affairs, 1987), not only technically (heat demand and specifications) and economically (profitability, financing options, uncertainties) but also psychologically (no core business, new forms of cooperation). The role of the government would be (i) to monitor the market, (ii) to adjust the cogeneration stimulation program when necessary (F6), and (iii) to disseminate (new) cogeneration knowledge among potential users (F3).

The Ministry of Economic Affairs also recognized that the optimal economic design of a cogeneration plant would be based on the heat demand (NEOM, 1987). In order to realize this, it was necessary to adjust the feed-in tariffs to such a level that avoided costs by the distribution companies would be reflected. By doing so, one of barriers identified earlier by NEOM was tackled (F5). To smoothen things even further, involvement of the distribution companies in the cogeneration projects would be preferable. Already in 1981/82, the electricity company of the city of Rotterdam took the initiative (F1) to build two cogeneration plants in cooperation with several industries (F3). Neither one of these projects was carried out because no agreements could be reached on the steam contracts (Blok, 1991). The industrial companies did not like to enter into long-term steam contracts, whereas utility did not want to take the risk of the industry stopping the purchase of steam. Moreover, utility could not get hold of the same investment subsidies as the industry, one of the barriers earlier identified by NEOM.

The solution to the problem was found by the chemical company AKZO Nobel and the regional utility EGD (now Essent) in 1983 (F1). They started an innovative cogeneration project, which became operational in 1987. The innovative element did not only relate to the state of the art technology used, but even more so to the ownership construction chosen (F2). This project was the first joint venture project in the Netherlands, which would serve as example for many other projects to follow (F3). In innovation system terms, one could say that AKZO and EGD were prime movers (F1). Joint ventures settled the earlier problem of steam contracts as both the industry and

<sup>1</sup>Wet Investeringsrekening-Energietoelag.

utility had a share in the joint venture. Joint ventures also became the basis for external financing by banks and private investors (F6). Advantage for the industrial partner was the lower internal rate of return required compared to industry-only projects, since cheaper capital was available. For the external financiers the risks of such projects seemed small due to the involvement of more than one partner: a decision to stop the project could no longer be made by just one partner (CWK, 1987).

An important driver for this trend was the separation of electricity production and distribution, which was enforced in the Electricity Act of 1989 (Ministry of Economic Affairs, 1989) and already announced in the draft act of 1987. Now, distribution companies were allowed to buy their electricity from the cheapest producer or to produce the electricity themselves, e.g. with cogeneration. The maximum allowed capacity was set on 25 MW<sub>e</sub>. In order to have access to larger capacities and further reduce dependency on the power producers, a joint venture construction with an industry was the optimal solution (Blok and Farla, 1996). Whereas earlier cogeneration projects mainly served the internal heat and electricity demand of industries, a new market (F5) opened up: the public electricity market.

The Electricity Act also tackled other barriers, which hampered further diffusion of cogeneration. The feed-in tariff for guaranteed and non-guaranteed grid delivery was settled and would be based on avoided fuel and capacity costs (F6). The re-supply issue was settled and back-up power contracts became significantly cheaper. Distribution companies were obliged to purchase cogenerated electricity, exported to the grid by industrial autoproducers (F7). Finally, local emission norms could no longer hamper diffusion of cogeneration (F7).

With the Electricity Act the diversification policy was abandoned once and for all. It had only been a few years earlier that the power producers, confronted with the unease of high fuel prices in the beginning of the 1980s, had come to the conclusion that new capacity should be focused on coal and nuclear energy. For this purpose, the construction of a few new coal-fired plants and two new nuclear units was anticipated. It was early 1986 when the Dutch Parliament had to approve of the new nuclear capacity. Approval might have been given if the nuclear accident at Chernobyl had not happened at that same time. The nuclear plans were frozen and the government had to decide on alternatives. At that time, coal seemed the most logical option to fill the nuclear gap (Harmsen, 2000). Oil was no longer an option for the production of electricity; furthermore, electricity prices were still instable due to fluctuations in the price of fuel. However, the power producers recognized that the emission standards for individual new coal-fired plants could be in conflict with the SO<sub>2</sub> and NO<sub>x</sub> emission ceilings of the electricity sector (Dinkelman, 1995). This opened up the road to natural gas in general and gas-fired cogeneration specifically, especially when at the same time the government decided to set

natural gas prices for cogeneration at the same level as those for power producers (Ministry of Economic Affairs, 1987) (F5, F6). The choice for natural gas as main fuel for central electricity production implied that prices on the Dutch electricity market would be dominated by the price of natural gas. As the ratio of gas and electricity prices is extremely important for the economics of a gas-fired cogeneration plant, a stable link (also called spark spread) between both prices—if gas prices rose, the electricity price would follow—would provide a solid climate for investment with a relatively low level of market uncertainty (F5).

To summarize: the road to success is dominated by many positive system functions. The government intentionally stimulated cogeneration especially by knowledge creation (F1), resources mobilization (F6), and market formation (F5). Entrepreneurs in the innovation system fulfilled important functions such as undertaking entrepreneurial activities (F1) and the diffusion of knowledge of this technology (F3). It was the design of the Electricity Act that unintentionally became a very important structural driver for change, since it stimulated the distribution companies to become active in the adoption of this technology.

### 3.3. The exploitation of success (1987–2000)

The climate change problem became a major topic on the political agenda after 1987 (World Commission on Environment and Development (WCED), 1987). It stimulated the Dutch government to further focus its energy policy, which was no longer merely legitimized by the saving of energy and energy costs, but also by the reduction of CO<sub>2</sub> emission (F7). The government started to sign voluntary agreements with almost all industrial sectors (F5). The aim of these voluntary agreements was to reduce the industrial energy demand by 20%. The industry obtained utter freedom in how to achieve this target (F4).

At the same time, the electricity sector came to an agreement with the Dutch government to reduce carbon dioxide emissions by means of an environmental action plan (EnergieNed 1991).

Joint venture cogeneration projects formed the perfect link between the voluntary agreements of the industries and the environmental action plan of the distribution companies, as both would be granted for the energy savings they achieved (F7). Due to the interests of the distribution companies, i.e. their aim to build up a strong position on the electricity market (F5) and the regulated feed-in tariffs (F6), cogeneration plants no longer needed to be designed to meet the electricity demand. This led to increased electrical capacities of the new-built plants and, consequently, to increased profitability of cogeneration (F5). Cogeneration could now perfectly benefit from the rapid development of medium and large-sized gas turbines (F2), both in terms of efficiency increase and investment cost reductions (Kouvaritakis et al., 2000).



In the period 1990–2000, the Dutch government spent €400–500 million (F6) for stimulating cogeneration (Boonekamp et al., 2002). More than half of this money (over €300 million) was spent in the period 1993–96 via the investment subsidy BSET, which aimed to stimulate investments in energy saving. In January 1997, a new policy instrument, EIA, which fiscally stimulates investments in energy saving technologies, replaced the former instrument. Between 1997 and 2000, about €90 million of government money was spent on the EIA instrument to support cogeneration (F6). In the 1980s, most subsidies had been reserved to industrial users but in this period the energy companies could also benefit via the joint ventures (Blok, 1991). Other investment related policy instruments were available for cogeneration in the 1990s (VAMIL, EINP, TIEB, NEWS) and amounted to another €100 million of government money devoted to cogeneration (F6).

The Dutch government not only supported cogeneration by financial stimulation measures, it also installed a cogeneration broker in 1987 (F3). This broker stimulated cogeneration by linking market parties (F3) and by providing information on the benefits of cogeneration (Jeeninga et al., 2002). Also it disseminated knowledge on cogeneration joint ventures (F3). It took over the earlier role of NEOM in the 1980s (de Jong, 2004).

From the user side, knowledge development (F2) and diffusion (F3) was taken care of by EnergieNed (the association of the electricity distribution companies), VEMW (the association of heavy industry), and several industry-specific sector associations such as, for example, in the paper and board industry.

The now well-functioning innovation system led to explosive diffusion of new cogeneration capacity. Subsidy funds, available for cogeneration, rapidly depleted (Blok and Farla, 1996). It soon became clear that the excessive growth of cogeneration would lead to a large electricity surplus. Reinforcement dynamics were expected to make this problem even worse: the price of central electricity production would increase due to lower base load demand (taken over by cogeneration), making cogeneration even more attractive because of the capacity component in the feed-in tariffs (Jeeninga et al., 2002). Therefore, the electricity production companies and distribution companies agreed on a temporary moratorium in 1994. For a period of 8 months no new cogeneration above 2 MW<sub>e</sub> would be ordered, the realization of 1400 MW cogeneration capacity was postponed to the year 2000, and the compensation for avoided capacity costs was lowered (Blok and Farla, 1996). The moratorium gave an extra impulse to the growth of small-scale cogeneration in the horticulture and services sector. Motivated and financed by money from the environmental action plan, the distribution companies now, more than ever before, considered small scale cogeneration as an important growth market without the restrictions agreed upon in the moratorium (Boonekamp et al., 2002).

After the moratorium was ended, the growth of cogeneration remained high, as can be seen in Fig. 1. In 1995, investment subsidies for cogeneration were terminated (Jeeninga et al., 2002), but several other measures to support cogeneration were left in place such as the special natural gas price and the exemption from ecotax (introduced in 1996) for natural gas and in-house consumed cogenerated electricity. In the year 2000, decentralized cogeneration capacity in the industry had increased to 3300 MW<sub>e</sub>, which was 700 MW<sub>e</sub> more than had been anticipated by the Commission on Cogeneration in the Industry in 1987. In the non-industrial sectors, decentralized cogeneration grew from almost zero in the 1980s to 1500 MW<sub>e</sub> (more than 3500 units!) in the year 2000 (source: CBS, Statistics Netherlands).

The additional energy savings by decentralized cogeneration in the period 1990–2000 amounted to 90 PJ of primary energy per year, which is approximately 5 Mton of avoided CO<sub>2</sub> emissions, assuming that the alternative for cogeneration would have been natural gas-fired power stations.

To summarize, the exploitation of the success period showed a well functioning innovation system. Looking back, many government actions were well aligned with the need of cogeneration adopters.<sup>2</sup> The voluntary agreements with the industry and electricity sector guided the search towards energy efficient conversion technology, market formation took place by good feed-in tariffs, resources were made available in the form of investment subsidies, and a knowledge broker took care of knowledge diffusion and the creation of legitimacy. As a result, the level of entrepreneurial activities became very high. Furthermore, the innovation system could make maximal use of structural changes in earlier periods.

### 3.4. The success story comes to an end (2000–06)

The term ‘decentralized’ is often confused with ‘distributed’. Whereas the latter has to do with plant size (distributed generation is about small scale electricity production, not only from cogeneration, but also from wind and solar energy), the former does not. The 450 MW<sub>e</sub> decentralized CHP plant in the southern part of the Netherlands serving DOW Chemicals and the 360 MW<sub>e</sub> decentralized cogeneration plant in the north of the country serving AKZO Nobel prove this point. None of the so-called “centralized” cogeneration plants in the Netherlands (a number of district heating schemes and a few plants serving industries) is as large as these two plants. The term “decentralized” has to do with ownership and the

<sup>2</sup>In this analysis we condense a long period of history. This logically leads to a great loss of empirical details. Looking back, we see that governmental actions were well aligned with the needs at that time, but in real time actors may very well have perceived this differently. One of the interviewees stated that he perceived the governmental actions during this period as a significant source of uncertainty, and that the logics were not always easy to grasp.



recent history of the Dutch electricity supply after the Electricity Act of 1989, when production and distribution of electricity were strictly separated.

When the Electricity Act of 1998 (Ministry of Economic Affairs, 1998) came into force, it was no longer relevant to make a distinction between decentralized and centralized cogeneration. Mergers between distribution and production companies totally changed the institutional framework of the Dutch electricity sector. Now, Essent (a merger between two production companies and several distribution companies) is by far the biggest player in the Dutch cogeneration market. The company owns small-scale cogeneration plants, large industrial units, and district heating schemes, and it is also involved in a number of joint ventures.

The Electricity Act of 1998 not only made the term “decentralized” meaningless, it also put an end to the success story of cogeneration. Special treatment of cogeneration stopped. Feed-in tariffs, which were formerly regulated and based on avoided fuel and capacity costs, now had to be negotiated in a competitive market. Special cogeneration tariffs for transmission and transport disappeared, which made back-up electricity for autoproducers quite expensive (Rijkers et al., 2002). In a liberalized EU electricity market, special regulatory treatment of cogeneration was no longer allowed.

After a few years it became clear that cogeneration had difficulty surviving in the liberalized market. Rising natural gas prices (linked to the oil price) stressed this point and worsened the situation. During off-peak hours (nights and weekends) the price of electricity was set by cheap coal and import electricity (Rijkers et al., 2002). In the 1990s, the Dutch electricity price was mainly determined by natural gas, which made the exploitation of cogeneration quite robust: rising gas prices would hardly affect the profitability of cogeneration (in fact it was the other way around: the competitive position compared to gas-fired power plants improved with rising gas prices!). After the market had been liberalized, it became difficult for cogeneration to even cover its marginal costs. The Dutch government recognized the situation and came up with new measures, approved by the European Commission, to support the exploitation of cogeneration: first with a feed-in subsidy for grid delivered cogeneration electricity (European Commission, 2001) and from 2003 onward with cogeneration certificates based on the CO<sub>2</sub> performance of a plant (European Commission, 2003) (F5, F6). In the period 2001–05, more than €400 million were spent (F6) to conserve the energy savings that had been realized in the 1990s (Harmsen and Menkveld, 2005a, b). However, the exploitation support turned out not to be sufficient to offer favorable prospects for new or replacement investments. Therefore, no substantial growth in cogeneration capacity is anticipated in the short term, except for small cogeneration units in the horticulture sector.

To summarize, market liberalization frustrated the well functioning of the cogeneration innovation system. In

terms of system functions, it can be stated that access to the public electricity market (F5) has become less favorable, due to a change in the institutional setting along with rising oil prices. Currently, the innovation system faces a status quo: market uncertainty hampers resource mobilization (F6). Venture capital is hardly available for new projects and the government reconsiders its support scheme (“cogeneration on an everlasting subsidy drip or not”) despite efforts by lobby organizations to convince the government that the subsidy should be increased (F7). At the turn of the century a clear vicious cycle is visible.

### 3.5. *Unlocking the vicious cycle*

The key to unlocking the current vicious cycle can be found in the functioning of the innovation system. The main function that is currently underperforming and negatively influencing all other functions is market formation. There seems to be a clear need for a long lasting change in the institutional structure that creates a clear market for cogeneration. Temporal subsidies and feed-in tariffs do not seem to be strong enough to deal with the highly volatile market dynamics of a liberalized market.

The knowledge (F2) to overcome the current situation is under construction: it seems that there is a need for a more flexible operation of cogeneration schemes, and that cogeneration should be made more tenable against fuel price fluctuations. The former could be achieved by technical solutions and reorganization of the industrial heat demanding processes. The latter could be realized by a decoupling of the natural gas prices and oil prices, innovative energy contracts for fuel, heat and electricity, perhaps a fuel shift, and more than likely more stringent CO<sub>2</sub> emission allocations, as cogeneration will definitely profit from high CO<sub>2</sub> prices being passed through in the electricity price. Strong climate change policy in general would help guiding the search to sustainable solutions (F4). As long as the share of renewable energy remains relatively small—both in serving electricity and heat demand, natural gas-fired cogeneration is among the most energy efficient solutions to be used for reducing CO<sub>2</sub> emissions. With such a policy, one just has to wait for the next entrepreneurs (F1) to realize a new innovative stock of cogeneration capacity and unlock the market.

## 4. Conclusions

First, we draw conclusions on the usefulness of the method. Like it was the case in several other studies, the functions of innovation systems framework proved to be a powerful tool in analyzing the reasons for success and failure of cogeneration in The Netherlands. We documented many events that took place in the evolution of cogeneration and all of them could be related to either one of the seven functions of innovation systems or to structural changes in the institutional setting. By doing so, we were able to describe the build-up of the cogeneration

innovation system over time. As a consequence, we were able to correlate the moment of take off for this technology to the situation where all system functions received sufficient attention. When only a few system functions were well taken care of, no take off was observed. When a few functions collapsed, also the diffusion of cogeneration stopped. Thus, in this case a well functioning innovation system had a large impact on technology diffusion. More case studies are necessary to generalize this observation for technology diffusion in general.

The empirical conclusions are the following. We have seen a very successful government in the stimulation of cogeneration technology. The Dutch government has focused on many system functions to boost the diffusion of cogeneration, starting with guidance and creation of legitimacy and following up by market formation and resources mobilization. The activities of the government were well aligned with the needs of cogeneration adopters. Other actors in the cogeneration innovation system performed complementary activities (knowledge diffusion, innovative entrepreneurial activities, mobilization of resources) so that all system functions received sufficient attention. Thus, in this case study we observe a well functioning innovation system, which in turn leads to a successful diffusion of cogeneration technology. This observation is important since it backs the functions of innovation systems framework. We also observe that a decline in system functioning directly has consequences for the diffusion pattern.

This case study also shows that the institutional structure is an important explanatory factor for system functioning. The electricity act in 1989 and the voluntary agreements to reduce energy use around 1990, for example, were not intended to stimulate cogeneration but nevertheless had a major positive influence on the functioning of the innovation system. Without these often-unintentional changes (with respect to cogeneration stimulation), diffusion would not have taken place the way it did. Furthermore, structural changes in the institutional settings, like liberalization of the electricity market and high gas prices, also influenced the diffusion of cogeneration in a negative way in the period 2000–06. Thus, innovation system functioning proved to be quite vulnerable for changes in institutional context. The reason for this seems to be the strong dependence of the innovation system on government actions. For emerging innovation systems around sustainable technologies this is unavoidable, but for full-grown innovation systems such as the cogeneration innovation system in the Netherlands, this is undesirable.

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