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Investigating the interaction between the introduction of the hybrid heat pump and micro CHP

Master Thesis, 45 ects

Sjoerd Sloterdijk, BSc, Science & Innovation Management, Faculty Geosciences, Utrecht University

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Supervisors:
[1] Dr. R. Harmsen, Department Innovation & Environmental Sciences, Utrecht University
[2] Prof. Dr. M.P. Hekkert, Department Innovation & Environmental Sciences, Utrecht University

Content

Summary

This research intends to investigate the interaction between two emerging competitive technologies in the Netherlands, the hybrid heat pumps (HHP) and micro combined heat and power (micro CHP). Studying emerging sustainable technologies usually arises from the environmental problems society faces nowadays. Energy production in our society is traditionally based on the combustion of fossil fuels which causes the emission of Carbon Dioxide (CO2), one of the greenhouse gases causing global warming. To reduce these emissions, new sustainable technologies like the HHP and micro CHP are being developed. By assessing the implementation process of such technologies, any hampering factors can be revealed. These hampering factors can be assessed to foster diffusion of the technology. One method to assess an implementation process, is through the theory of Technological Innovation Systems (TIS). Technological Innovation Systems apply a systematic approach to understand technological change at the micro level [Hekkert et al, 2007]. Seven system functions are used to describe this technological change: (F1) entrepreneurial activities, (F2) knowledge development, (F3) the role of knowledge diffusion, (F4) guidance of the search, (F5) Market formation, (F6) resource mobilisation and (F7) the creation of legitimacy. These seven system functions jointly determine the successfulness of the TIS. However, during TIS analysis competing technologies are seen as part of the environment instead of including them in the analysis, while it is plausible to think that a competitive technology has an influence on the performance of the technology under investigation. Raven (2009), for example, showed in his article about niche interactions that national differences like regulations and subsidy schemes were a clear reason for the differences in performance of the implementation process of biogas in each country. When functional differences occur between technologies competing for the same market, it might create a competitive advantage for one technology, and thus influence the performance of the implementation process of the other technology. The purpose of this research is thus to investigate whether a competitive technology has an influence on the performance of an implementation process under investigation, and should therefore be included in a TIS analysis.

To find an answer to this problem both the implementation process of the HHP and micro CHP have been assessed. Data has been gathered in two ways; (1) by holding 9 interviews among important actors in the field of the HHP and micro CHP, and (2) through the analysis of scientific reports, newspapers, professional journals, grey literature and other databases. This has highlighted any driving and hampering factors of the process. Subsequently, a cross-case analysis has indicated any differences between the Technological Innovation Systems. It was up to the researchers to investigate whether these differences were caused by the presence of the other competitive technology, creating an interaction.

The evaluation of the data led to some interesting findings, both in the assessment of the Technological Innovation Systems and during the cross-case analysis. The TIS analysis of the HHP showed for example that the main driving force in this sector has been the entrepreneurial activity (F1). Entrepreneurs initiated the foundation of an interest group, they dealt with technological difficulties and organised trainings to enhance knowledge diffusion. During the process they always sought for opportunities to foster the diffusion of the HHP. However, several factors have counteracted these activities. One of these factors has been the lack of involvement of the Dutch government. This has been reflecting upon several events. First of all, the subsidy program was not designed properly, and secondly, the government lacked the ability to make decision on policy strategies, and lacked communicating this with

the actors in the field. This resulted in a lack of environmental regulations in the existing housing sector, and decreased incentives for investing in the HHP market.
The TIS analysis for the micro CHP showed a somewhat different involvement from the government. Especially in the earlier stages of the process, the Dutch government has stimulated the process through higher subsidy levels and extra funding. This had resulted from the main driving force in the implementation process of the micro CHP namely; the extensive support from major actors such as Gasterra, a Dutch gas trading company, and the government. The performance in the system functions guidance of the search (F4) and creation of legitimacy (F7) illustrated this. Eventually this also led to an increase in funding, to an increase in field tests with the technology to enhance knowledge, an increase in awareness for the technology, and an increase in expectations. But as the process progressed, the support from the government reduced. In an official letter from the minister of economic affairs, the government stated that the subsidies had not led to the desired cost reductions and learning curves, forcing them to cancel any sequels for the subsidy programs. This meant that the major bottleneck for implementing the micro CHP, its high investment costs, was strengthened. This, combined with the lack of regulations in the existing housing sector, has decreased incentives to invest in the micro CHP sector drastically.
However, in both processes various activities are undertaken to keep fostering the diffusion of the technologies. An example in the HHP sector is the shift of focus towards the new housing estate. The regulations in this sector ensure more incentives for investing in sustainable technologies. The micro CHP sector has founded an organisation in which various housing corporations are accommodated that can jointly place orders at Remeha, a producer, to reduce the costs per micro CHP.

The cross-case analysis indicates that interaction patterns exist between the HHP and micro CHP. These have influenced the performance of either process. In the development stage the difference in lobby strength (F7) showed that a competitive technology can overshadow lobbying activities of a technology under investigation. As a result, the lobbying activity for the HHP did not have the desired impact, as they cannot compete with the lobby strength of large companies such as Gasterra and Remeha. The position of the government also played a major role in this. Moreover, this led to an interaction in resource mobilization (F6) because the micro CHP was able to gather more funds for their project. It also led to an interaction in guidance of the search (F4), opinions on the micro CHP were more positive than for the HHP. One could say that a competitive advantage for the micro CHP existed. However, the micro CHP still faced a major bottleneck due to its high costs. A micro CHP is 10.000 Euros while the HHP is only 3500 Euros. Besides, the HHP is better applicable in the new housing estate, where the more stringent regulations have increased incentives to invest in sustainable technologies. These factors, combined with the fact that the government cancelled any sequels for the subsidy programs, have created a shift in competitive advantage. The micro CHP is more dependent of subsidy programs and stringent regulations. This does not mean that it really enhanced diffusion of the HHP. Both technologies still face similar problems. Therefore, the interaction could focus more on a cooperation between the technologies. Combining their lobby actions (F7) to exceed pressure on the government might realize the implementation of more sustainable energy policies for example.

Eventually this research indicates that differences in the functioning of an implementation process between two emerging competitive technologies can lead to interaction patterns. Interaction patterns can create a competitive advantage for one technology, hampering the process of the other. So far, competing technologies were seen as part of the environment instead of including them in the TIS analysis. It is important to over think this approach and to think of a measure to include competitive technologies in the TIS analysis.

Abstract

Technological Innovation system (TIS) analyses are frequently used to describe technological change. By using a framework that focuses on the most important processes that need to take place in technological development and diffusion, the successfulness of an implementation process can be analyzed. But up till now, this framework saw competitive technologies as part of the environment, instead of including them in the analysis. This research builds upon one empirical case study, comparing the technological innovation systems of the hybrid heat pump and micro combined heat and power, to test whether any interaction patterns can be indicated between the implementation processes of two competing technologies. We will give a TIS analysis of both technologies, and execute a cross-case analysis to highlight the interaction patterns between them. The results identified some clear interactions showing that a competitive technology does influence the fulfilment of the system functions in the implementation process.

1. Problem description

Energy production in our society is traditionally based on the combustion of fossil fuels which causes the emission of Carbon Dioxide (CO2), one of the greenhouse gases causing global warming. Many countries are taking measures to reduce their greenhouse gas emissions. The EU, for example, mandates a 20% reduction in greenhouse gas emissions by 2020, compared to 1990. To support target achievement the European Commission implemented several climate related policies [EC, 2010].

The residential sector, one of the main consumers of energy, is an important target area of these policies [Tolga Balta et al, 2010]. This also applies to the Netherlands, where the residential sector consumed about 16% of the total primary energy consumption in 2008 [MONITweb, 2011]. For space heating purposes only, the residential sector was, in 2008, responsible of about 16% of the total primary energy consumption. The majority of this energy is used in existing houses that are, in general, not as well insulated as new houses.

This paper focuses on the existing housing market in the Netherlands. For space heating, the condensing boiler is the dominating technology. However, more efficient options are emerging. This paper deals with two technologies, namely the hybrid heat pump (HHP) and micro combined heat and power (micro CHP). So far these technologies played a limited role in the market of heating applications in the Netherlands. Even though, these technologies are very applicable for the existing housing market in the Netherlands.

Both technologies have just been introduced in the market. Therefore, this research will try to give an insight in their implementation process by assessing and comparing their Technological Innovation Systems (TIS) in the Netherlands. The TIS approach has been used to study emerging technologies and technological change [Hekkert and Negro, 2009]. The connection between TIS and technological change is that the emerging technology is developed within the context of a TIS.

However, one problem with TIS analysis so far has been that competing technologies were seen as part of the environment, instead of including them in the analysis. Raven (2009), for example, showed in his article about niche interactions that national differences like regulations and subsidy schemes were a clear reason for the differences in performance of the implementation process of biogas in each country. When such functional differences occur between technologies competing for the same market, it might create a competitive advantage for one technology. This might influence the performance of the implementation process of the competing technology. For example, differences in subsidies between two competing technologies might create a competitive advantage for the technology receiving most money. Therefore, this research investigates whether such differences create some kind of interactions between two competing TIS trajectories.

This resulted in the following research question:

> *How do the implementation processes of two emerging competitive technologies in the Netherlands, the hybrid heat pump and micro CHP, interact?*

To embark in a transition towards a more sustainable environment in the existing housing sector in the Netherlands, both the HHP and micro CHP can play a key role. Their energy savings potential could lead to a significant emission reduction in the existing housing sector in the Netherlands [Ecofys, 2009]. But, these markets are still in its infancy, and need to be investigated in more detail, also to find get an answer to the research question. It is therefore important to do a conventional TIS analysis for both technologies. So next to the research question, the following sub questions have been defined.

Sub questions:

- What factors drive, or hamper, the implementation process of HHP and micro CHP?

- What kind of interaction can be found between the entrepreneurial activities of micro CHP and HHP?

- In what way does the government support the implementation of the HHP and micro CHP?

- How have the networks of actors in the HHP market and micro CHP market been developed?

- How can the structure of the TIS be defined?

2. Justification

The contribution of this research to the existing literature is twofold, which will be explained in more detail in this section

First of all, this research investigates the influence between the development of two types of Technological Innovation Systems, namely the hybrid heat pump and micro CHP. Because these technologies are competing, and they are assessed in the same way, a comparison can give more insights in the interaction between the two. Although comparisons between innovation systems have been made before, these were between National Innovation Systems (NIS) and between Technological Innovation Systems at national level [Hillman et al, 2008; van Alphen, 2009]. A Comparison between Technological Innovation Systems of competing technologies has not yet been done. During TIS analysis, the competing TIS trajectories were, until now, seen as part of the environment and were not included in the analysis. This research will therefore contribute to the existing literature, as it investigates whether a competing TIS trajectory has an influence on the TIS trajectory under investigation. By assessing two Technological Innovation Systems relative of each other, one can find out how they interact and find out whether that influences the functioning of the systems in any way.

Additionally, this research investigates the implementation processes of two sustainable technologies. An assessment of the implementation process of Micro CHP from a TIS perspective has already been done in England [Hudson et al, 2011], but not for the Netherlands. Therefore, this research might highlight any new hampering or driving factors in the implementation process in the Netherlands.
In the HHP field, some research has been conducted, but most research has focused on heat pumps in general, instead of the hybrid variant. Furthermore, research mainly consists of potential studies [Ecofys, 2009] or advances in heat pump technologies [Chua et al, 2010; Chua et al, 2002]. So this research will again deviate from previous conducted research as it tries to give an insight in the implementation process of the hybrid heat pump. This can highlight any hampering, or driving factors in the process and allows to create a strategy around it to foster the implementation process. Furthermore, a market assessment of Senternovem (2009) has pointed out that the hybrid heat pump market in the

Netherlands is still very small and lags behind other European countries. But, due to environmental regulations and rising energy prices, producers of heat pumps see more and more possibilities in the upcoming market. This shows the importance of such an implementation study at this time.

3. The technologies

As described in the previous section the implementation process of two heating applications for the existing housing sector will be assessed. To get a better understanding of how they operate, and of their applicability, they will be described in more detail in this section

3.1 The hybrid heat pump

A heat pump is an electrical heating application that transfers heat from one location (the source) at a lower temperature, to another location (the sink) at a higher temperature using mechanical work. It can be used to provide both heating and cooling. A heat pump is a common used technology and can be found in everyday equipment such as refrigerators, freezers and air conditioners. The application to provide building space heating is more recent, and is also the reverse cycle of the other three applications mentioned.

The operating principles of a heat pump are based on the physical principle: *when a gas is compressed into a higher pressure state, the temperature will rise* [Dutch Heat Pump Assocation, 2011]. A heat pump uses this principle in a closed system to pressurize the gas with a compressor until the corresponding temperature is high enough to heat a building for example. This closed system is indicated as follows (figure 1); the working fluid, in its gaseous state, is pressurized and transferred by a compressor (4). It then flows through the condenser (1) in which the fluid is condensed into a high pressure moderate temperature liquid. During this stage the heat pump loses its heat to the environment. The fluid then transfers to a pressure lowering device called an expansion valve (2). The low-pressure liquid then transfers through another heat exchanger, the evaporator (3), in which it absorbs heat and boils. The cycle is then repeated. This cycle is illustrated in figure 1.

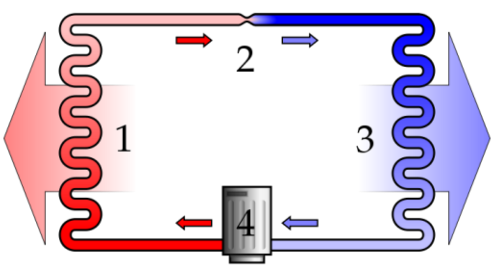

Figure 1: The heat pump cycle

There are various forms of heat pumps, differing in the source of which they extract heat:

- Air source heat pumps, extract heat from outside air;
- Exhaust air source heat pumps, extract heat from exhaust air of buildings;
- Geothermal heat pumps, extract heat from the ground
- Water source heat pumps, extract heat from water.

This research focuses on the hybrid heat pump, which is a relatively small air source heat pump with limited capacity, combined with a condensing boiler [Ter Steeg and Thijssen, 2011]. The heat pump delivers the heat during moderate outside temperatures, i.e. during a limited heat demand. The

condensing boiler delivers the heat during low outside temperatures when more power is needed. Moderate temperatures are common during most part of the heating season, which means that the heat pump delivers a significant share of the total heat demand.
The hybrid heat pumps show minor differentiations. The components can be integrated in one HHP unit, the condensing boiler can be delivered separately, or the condensing boiler is combined with an exhaust air source heat pump. Although some people see them as different technologies, this research accommodates them as one technology.

The HHP is most efficient when the heat pump part covers as much of the heat demand as possible. But the heat pump does not have the capacity to work efficiently in every temperature difference. To increase the efficiency and the coverage of the heat pump, various measures can be taken. The efficiency of the heat pumps strongly depends on the existing delivery system. There are two types of delivery systems, high temperature (ht) delivery systems and low temperature (lt) delivery systems. Ht-systems in the Netherlands usually have a delivery temperature of 90^0C and a return temperature of 70^0C, lt-systems usually have a delivery temperature of 55^0C and a return temperature of 40^0C. Although the HHP is implementable in both systems, the efficiency of the heat pump will increase drastically when installed with a lt-system where the temperature differences are smallest. But in a poorly insulated building delivery temperatures of 55^0C are not always sufficient to keep a house warm. To implement a lt-system in the existing housing sector, you need to reduce the heat transmission losses through increasing insulation [Ter Steeg and Thijssen, 2011]. Increasing insulation reduces the heat demand which means that less capacity is needed to heat a building to the desired temperature.
Ecofys (2009) has illustrated the effect of increasing insulation in the existing housing sector. Without insulation a CO2 emission reduction of 1,6 Mton per year can be achieved with the HHP. This equals a cumulative number of 2 million installed hybrid heat pumps in 2030, assuming 40% of the replacement market (baseline scenario). However, improving insulation in a standard household, build between 1960 and 1980, results in an increase of CO2 reduction potential from 300 kg/year to almost 450 kg per year [Ecofys, 2009].

Hybrid heat pumps have a Coefficient Of Performance (COP) around 3.0 to 4.0. This means that for every unit of electricity, 3 to 4 units of heat are produced. In comparison, a conventional boiler only reaches efficiency of 107% at higher heating value. One must remark however that electricity is produced at an efficiency of 45%.

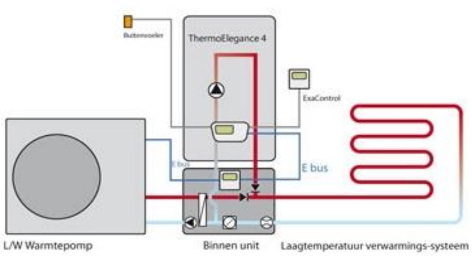

Figure 2: The HHP, an installation from AWB

3.2 Micro Combined Heat and Power

A micro CHP unit is based on the well-known idea of cogeneration, seen in electricity plants. A Micro CHP a type of condensing boiler that generates heat and electricity. The ability to generate electricity can be based on three types of technologies; external combustion, internal combustion and fuel cell [microwkk.nl, 2011]. Within these three categories another seven categories can be distinguished. This research focuses on the Stirling engine (external combustion) because it is the furthest in development [Goudswaard et al, 2008].

The first Stirling engine was developed early 1900s. From then on it is been used in small niche markets like shipping and space engineering. A Stirling engine is a heat operating engine that uses the expansion and compression of a gas to produce mechanical work. The general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle.
There are various types of Stirling engines like the alpha, beta and gamma Stirling engine, but a micro CHP is equipped with a free piston Stirling engine (see figure 3). Especially developments in space engineering have led to a compact and robust engine applicable for micro CHP units in households.

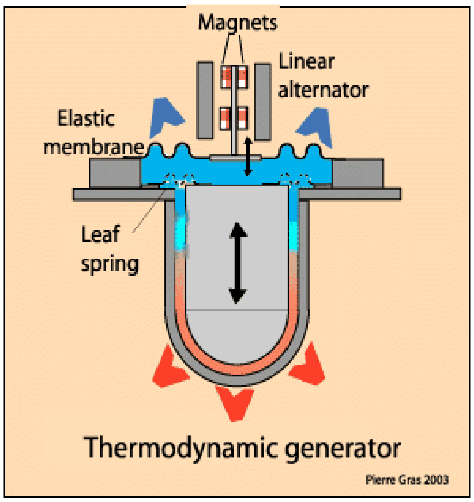

Figure 3: the fee piston Stirling engine

In a free piston Stirling engine a cylinder is heated from the outside to expand the gas inside. This expansion is the thriving force behind the movement of the piston. By moving the heated gas to a cool area, the volume reduces again. These volume differences create a cycle that keeps the piston in motion [Goudswaard et al, 2008]. The low temperature heat released during the process is used for heating; the mechanical energy released by the moving piston is used for generating electricity. In a free piston Stirling engine the piston delivers electricity, via an electromagnetic field, to a linear generator. Condensation of the combustion gases and cogeneration of heat and electricity creates a high overall efficiency.

Although a micro CHP commonly consumes more gas than a condensing boiler, this is compensated by generating electricity. A m3 of gas, which costs 0,59 Euros, can generate 10 kWh electricity, costing 2,20 Euros [Nuon, 2011]. When a significant amount of electricity is produced, the price differences between gas and electricity will make the micro CHP economically beneficial. To produce a significant amount of electricity, more gas is needed. Therefore, the micro CHP is best applicable in households consuming 2000m3 gas per year or more.

On average, a household consumes around 2000 m3 gas per year. In that case the micro CHP generates around 1500 kWh electricity, which is 60% of the total electricity demand of such a household. These efficiencies lead to a reduction potential of 1 Mton CO2/year in the Netherlands [ECN, 2008]. This is based on the baseline scenario. Improving insulation in households is not favourable because this will reduce the gas consumption and thus the electricity production.

4. Theoretical framework

Innovation is increasingly considered crucial to deal with the negative side-effects of economic growth [Hekkert and Negro, 2009]. A strong need has developed for studying technological change and emerging technologies to influence the direction and speed of innovation and enhance economic growth. Numerous theories have introduced new concepts to try to describe this technological change [Rogers, 1962; Geels, 2001; Hekkert et al, 2007]. Earlier theories, like Rogers (1962), developed concepts mainly focussing on describing the successfulness of a technology without dealing with external factors on the system level. Nowadays, theories do not describe technical change in the narrow sense, but describe the development of a technology in interaction with the system in which it is embedded [Hekkert et al, 2007]. Geels (2001) for example, describes in his theory of Multi-level perspective how technological transitions come about, and how this involves social dimensions like regulations, user perspectives and industrial networks. Describing technological change alone is not sufficient.

This research focuses on the implementation process of two technologies. To that extent, Geels' (2001) theory of multi-level perspective is not applicable because it describes the transition of an entire technological regime. A technological regime is defined by Rip and Kemp (1998) as:

"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."

The definition explains that technological regimes represent the entire infrastructure and network of actors of the embedded technology, which makes the artefacts (i.e. technologies) just one part of the technological regime. This research intends to have a more particular focus on the technologies without neglecting the systematic character of technological change. Therefore this research uses the theory of Technological Innovation Systems (TIS), developed by Hekkert et al (2007), to describe technological change.

The definition for Technological Innovation Systems, as defined by Carlsson and Stankiewicz (1991), shows the more narrow focus on one particular technology:

A TIS is *"A network, or networks of agents interacting in a specific technological area under a particular institutional infrastructure to generate, diffuse, and utilise technology".*

Technological Innovation systems have emerged from the Innovation System (IS) approach, which presents insights in the factors that explain processes of innovation [Lundvall, 2002]. The central idea behind the IS approach is that innovation and diffusion of technology are both an individual as a collective act [Hekkert et al, 2007]. It encompasses firm dynamics as well as adoption mechanisms. An IS can therefore be defined as:

"The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies" [Freeman, 1987].

TIS applies this systematic approach of IS in order to understand technological change. Although IS approach is a very heuristic framework to describe technological change, is still suffers from two major flaws [Hekkert et al, 2007]. Firstly, it is too static, and secondly, it lacks sufficient attention on the micro level. To solve this problem, Hekkert et al (2007) have defined a framework that focuses on the most important processes that need to take place in technological development and diffusion. Based on different categories and empirical studies at Utrecht University [Negro et al, 2006; Suurs and Hekkert, 2005], these processes have been defined as the seven functions that can be used to describe this technological change; (F1) entrepreneurial activities, (F2) knowledge development, (F3) the role of knowledge diffusion, (F4) guidance of the search, (F5) Market formation, (F6) resource mobilisation and (F7) the creation of legitimacy. These seven system functions jointly determine the successfulness of building the structure of TIS [Suurs et al, 2009], which consists of three elements namely actors, institutions and technologies. These elements are merely the building blocks of the TIS, and are, moreover, linked together.

4.1 System functions

As is stated in Suurs et al (2009), for an emerging technology, a TIS has to be build up. This build-up process may only be analysed by studying the key activities, e.g. system functions. These key activities jointly determine the successfulness of the TIS. Firstly by the degree of presence of each function, and secondly by the way they interact. Therefore these functions require some further explanation.

The first system function is *entrepreneurial activity* (F1), which comprises the presence of active entrepreneurs. The presence of active entrepreneurs is a first indication of the performance a TIS. Their role is to turn the potential of new knowledge, networks and markets into concrete actions to create new business-opportunities and as a result, benefit from them. Entrepreneurs can either be new entrants, or incumbent firms that diversify their business strategy to benefit from new technological developments [Hekkert et al, 2007].
Entrepreneurs are necessary in a TIS to cope with the large uncertainties in new markets. They experiment with new technologies to generate more knowledge about it, and thus, many forms of learning take place.

The second system function is *knowledge development* (F2). Knowledge development is at the heart of any innovation process [Hekkert et al, 2007]. Therefore it is a prerequisite of the successfulness of a TIS. This function comprises “learning by searching” and “learning by doing”.

The third system function is *knowledge diffusion* (F3) through networks, which is the exchange of information. According to Carlsson and Stankiewicz (1991) exchanging information is the essential function of networks. Especially in a heterogeneous context, when R&D is linked to governments and markets. In that case, policy decisions should be based on the latest technological insights. Furthermore, an increase in knowledge diffusion can strengthen a network as a whole because exchanging knowledge can lead to new technological insights and new technological developments.

The fourth system function is *guidance of the search* (F4), which refers to those activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users [Hekkert et al, 2007]. An example is the long term goals set by governments to reach a certain reduction in greenhouse gases. In that way, unlike functions 2 and 3, guidance of the search shows that technological change is not autonomous. But, guidance of the search is not solely a governmental or market influence, it is often an interactive and cumulative process of exchanging ideas between technology producers, users and other actors, in which the technology is not a constant but a variable.

Vague ideas are tried out in experiments, and the successfulness of the experiments is communicated to other actors, leading to expectations on a certain technology. This means that high expectations on a specific technology can generate momentum for change in that specific direction, and creating incentives for firms or organizations to enter the market.

The fifth system function is *market formation* (F5). For an emerging technology, a market may not exist, or is greatly under developed; customers have not yet been articulated, price/performance of the new technology is poor. New technologies usually have difficulty to compete with embedded technologies because they are still inefficient and expensive [Hekkert et al, 2007]. In that case, they only have a few advantages or none at all, resulting in a lot of uncertainties for entering the market. Therefore, these technologies should be developed in protected spaces, for example niche markets, to reduce the risk of investmenting. Within such an environment, recognition can be created for a new technology and expectations can be developed. Another possibility is creating a temporary competitive advantage by favourable tax regimes.

The sixth system function is *resource mobilization* (F6), which is basically the allocation of resources to make knowledge production possible [Hekkert et al, 2007]. This does not only entail financial resources, but also human capital and complementary assets. Human capital means the ability to find skilled employees, and by complementary assets you must think of complementary products, services or network infrastructure.

The seventh and final system function is *creation of legitimacy* (F7), which involves advocacy coalition to function as a catalyst to stimulate creative destruction. This function is thus somewhat related to market formation, though with a major difference that this function focuses on a catalyst to strive to market introduction. These advocacy coalitions put a new technology on the market, lobby for resources and tax regimes and, in that way, create legitimacy for a certain technological trajectory [Hekkert et al, 2007].

Analysing how the seven system functions are fulfilled is the first part of the determining the successfulness of a TIS. The other part is investigating how they interact. Studies have namely shown that the interaction between system functions lead to virtuous and vicious cycles [Hekkert and Negro, 2009]. Where positive interactions between system functions were a very important mechanism for change, negative interactions hampered the implementation process. For example, a clear legitimacy can have a positive effect on knowledge creation. However, per stage of the implementation process, specific interactions are important for the successfulness of the TIS. The stages that can be distinguished are the (1) *pre development stage*, in which the technology first emerges and an early system is developed, (2) the *development stage*, in which the working prototype should be commercialized, (3) the *take-off stage*, in which commercial application of the technology is a fact, (4) the *acceleration stage*, in which a market is formed and one aims at increasing productions, and (5) the stagnation stage, in which diffusion of the technology stagnates. In the latter stage, complete market penetration is a fact which means that all system functions are fulfilled. The other stages and their interaction patterns are illustrated in figure 4.

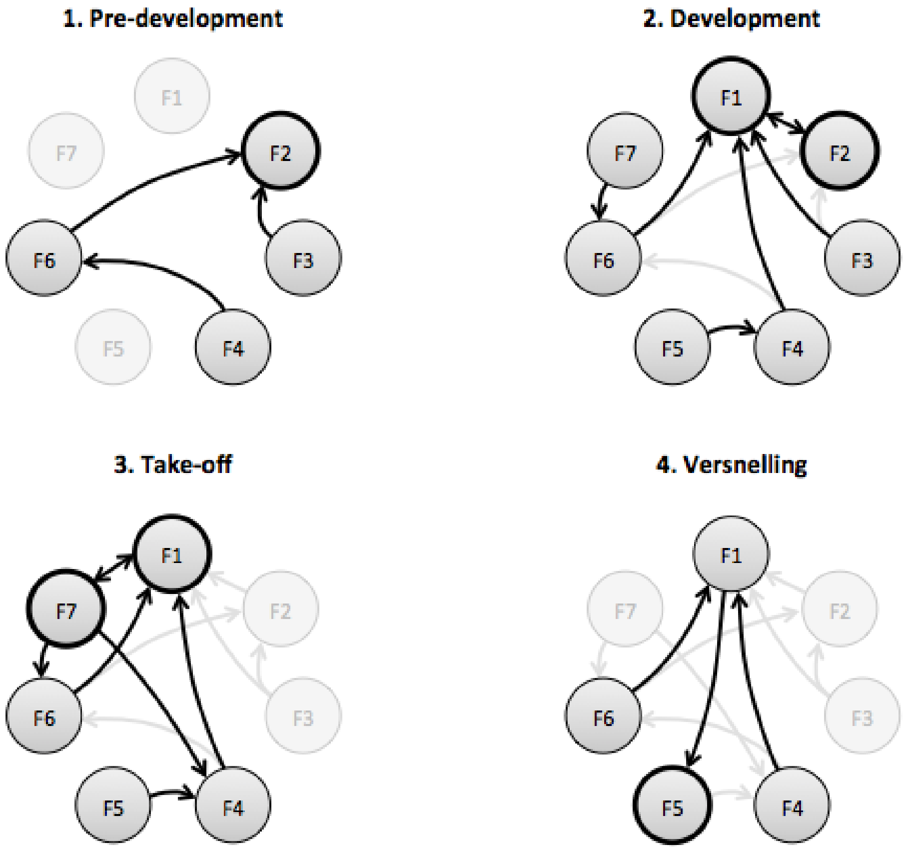

Figure 4: Important interaction patterns between system functions per stage of the implementation process [Hekkert et al, 2011].

5. Methodology

This research intends to investigate the interaction between two implementation processes using the theory of TIS [Hekkert et al, 2007]. This will be done through an empirical research. The purpose is to contribute to the theory of TIS in whether competitive technologies influence the successfulness of Technological Innovation Systems.

5.1 Data Collection

Data has been collected in two ways; (1) interviews with incumbent firms, and (2) the analysis of scientific reports, newspapers, professional journals, grey literature and other databases. It consisted of qualitative data. The analysis of reports etc. was mainly used for background information, to collect events to back up the data from the interviews and to provide examples for statements made during the research. The interviews were held with various actors within the field of hybrid heat pumps and micro CHP units. Not only producers of these technologies, but also with independent knowledge institutions, both governmental and non-governmental institutions and interest groups. The list of people interviewed is presented in table 1.

Case 1: HHP	***Name of the company***	***Name of the interviewed***	***Function within the company***
Producers:	Itho Daalderop	Paul van Dijk	Product Manager
	Inventum	Rob Verbrugge	Product Manager
	Techneco	Pieter van Alphen	Founder/Owner
	Vaillant/AWB	Gerard van den Bergh	Product Manager
Interest group:	DHPA	Peter Wagener	Chairman
Governmental intitution:	Agentschap NL	Onno Kleefkens	Senior Adviser
Case 2: Micro CHP			
Producers:	Remeha	Paul Gelderloos	Technical Innovation Manager
	Vaillant	Sander Rutten	Product Manager
Gas trading company	Gasterra	Hans Overdiep	Manager Energy Transition

Table 1: The interviews

The table shows that a sample of 9 interviews has been done throughout the sector. On top of this, two telephone interviews have been held with Marcel Klootwijk, one of the initiators of the HHP, and Rob ter Steeg from TNO. The advantage of interviews in this particular case is that interaction patterns between both cases are easier to identify because they can be highlighted and confirmed by the interviewed. The same holds for identifying the hampering conditions within the TIS, through interviews one can give reasons behind the lack of functioning of the system. However, the difficulty with interviews is that the relevance of the data depends on the orientation of the questions. To formulate significant interview questions you need to operationalize the concepts of the TIS in order to measure them. A clear operationalization should lead to relevant indicators and relevant interview questions.

5.1.1. Operationalization

The depending variable in this research is *"the functioning of the implementation processes of HHP and micro CHP".* Within the theoretical framework it became clear that the functioning of an implementation process can be described by analysing the seven system functions. However, the empirical operationalization of the system functions is not always as straightforward [Bergek et al, 2008]. Various TIS analysis have been done with differing operationalization schemes [Hekkert et al, 2007; Dosi et al, 1990; Bergek et al, 2008]. These inquiries have been used to develop an operationalization scheme suitable for this research. Within this scheme, each system function has been divided into several indicators which in their turn have been used to develop interview questions. In the theoretical framework a description of the system functions has already been given, so this section will continue on that basis to develop suitable indicators for each system function.

<u>Entrepreneurial activity (F1)</u>

A TIS evolves within a considerable uncertainty in terms of technologies and markets. The presence of entrepreneurs is therefore viable for the evolvement of a TIS. Their main form of reducing uncertainty is exerting *entrepreneurial experiments* [Bergek et al, 2008]. Entrepreneurial experiments usually entail experiments with the technology and aim at generating more knowledge about the technology. Generating knowledge results in a better understanding of the technology and enhances the probability of success. In the beginning of the process such experiments may include lab tests in which the technology is still under development. In the continuation of the process, these lab tests may be exchanged for field tests to be able to increase the performance of a technology.

The presence of entrepreneurs can be analysed through mapping the number of *new entrants,* including the number of diversifying firms. New entrants increase competition among the field and increase the change of successful experiments.

- Entrepreneurial experiments (lab tests, field tests)
- New entrants

Knowledge development (F2)

Knowledge development can be analysed by a range of indicators. Knowledge is usually placed at the heart of the TIS, which makes it an important function. You need to capture the breadth and depth of the current knowledge base, and how it has developed over time. This will be measured through analysing *R&D projects*. However, the degree of knowledge development depends on the number and orientation of the R&D projects, so this will be included in the interview questions. To include the degree of importance of the R&D projects, *the investments in R&D* will be compared to the total number of investments. Still, R&D projects do not highlight the effectiveness of knowledge development. Therefore *the number of patents* on the technology will be analysed to indicate the output of R&D activities [Mowery et al, 1996].

- Number of R&D projects
- Investments in R&D
- Number of patents

Knowledge diffusion (F3)

Knowledge diffusion entails the transfer of knowledge from one actor to the other. One measure to do this is organizing *workshops and conferences to a specific technology*. However, the rate of knowledge diffusion at these conferences depends on the degree of participation of relevant actors. Therefore the interview questions should also entail whether enough relevant actors participate at such gatherings.

The second indicator used is *the size of the network of actors*, on which the interview questions should entail the variables “number of actors” and “the diversity of actors”. The latter highlights the layers in the implementation process, in which suppliers and producers are examples of different layers. The more layers are present in a TIS, the more difficult knowledge diffusion will be. Furthermore *collaborations* also increase knowledge among the network, because they increase the knowledge base of the involved actors. Examples of collaborations are joint ventures, R&D collaborations, strategic alliances etc.

- Number of workshops and conferences devoted to the technology
- Size of the network of actors
- Collaborations.

Guidance of the search (F4)

Guidance of the search basically involves exceeding influence on the direction of search within the TIS, in terms of competing technologies for example. One measure is to raise *expectations* for the technology. Through raising expectations one can generate momentum for change in that specific direction. Another example of exceeding influence on the direction of search is *setting specific targets for a technology*. Specific targets aim at the use of a particular technology. In that case, the industry will in some way be forced to change the course of direction to that technology. A final indicator that might change the direction of search is *the involvement of lead users.* Lead users can give clear signals on the attractiveness of a technology, and give expectations of the future market. Furthermore they can give an idea of market demands on specific technologies.

- Raising expectations
- Setting specific targets for a technology
- The involvement of lead users

Market formation (F5)

In entrepreneurial activity (F1) is already described how entrepreneurs can deal with uncertainty, this function describes how to reduce uncertainty for entering a market. One indicator for reducing uncertainty in market formation is *setting specific tax regimes for a technology.* This entails increasing taxes on fossil fuels to reduce the pay back period for sustainable technologies. Often emerging technologies are too costly to compete with embedded technologies, tax regimes reduce these cost differences. Another indicator used is the implementation of regulations stimulating the use of sustainable technologies, i.e *setting environmental standards*. Such standards oblige the industry to implement a specific share of sustainable technologies, and thus insure a certain amount of sold products.

Apart from reducing risks for investing in an emerging market, the analyst also needs to know in what market stage the technology is in, because each market stage encompasses different activities for successful TIS development [Bergek et al, 2008]. For example, in the beginning of the process, knowledge development and entrepreneurial experiments are very important. In later stages of the process for example regulations and interest groups become more important. Therefore, you need to analyse what stage the technology is in. This will be done in two ways, by analysing the *maturity of the market*, a third indicator, and through analysing the number of *installed units* of a technology, the fourth indicator.

- Specific tax regimes for a technology
- Environmental standards
- Maturity of the market
- Installed units

Resource mobilization

Measuring the allocation of financial resources is not in particular difficult. Funding can be done in several ways, this research used the indicators; *subsidies* issued by the government, and *outside corporate funding*. By outside corporate funding you must think of corporate financers not involved in development of the technology. However, resources do not only entail financial capital, but human capital and complementary assets as well. These are more difficult to measure. Interviews give the solution to this problem; the interviewed has simply been asked whether or not they have enough skilled personnel and complementary assets.

- Subsidies
- Outside corporate funding
- Human capital
- Complementary assets

Creation of legitimacy

Creation of legitimacy is mainly influenced by the *presence of interest groups*. They can function as a catalyst to stimulate creative destruction. A first indicator is therefore to investigate whether or not these are present. Secondly, you need to analyse their *lobby actions*, and the degree of influence of these lobby actions. This means that you need to analyse how their involved, and in which projects. The degree of influence of these projects will be measured by analysing if society is *aware of the technology*, for example through how it is depicted in the media (newspapers, scientific journals etc.), or analysing the public opinion towards the technology.

- Presence of interest groups
- Activities towards the technology
- Awareness of the technology

Concept	Dimension	Indicators	Examples of questions
	Entrepreneurial activity	• New entrants • The number of experiments with the new technology.	• How many producers are active in the micro CHP sector at this moment? • How many entrepreneurial experiment has your company carried out in the HHP sector?
	Knowledge development	• R&D projects, • Number of patents • Investments in R&D	• Does your company have patents for the HHP technology? • How much money does your company spent on R&D? ○ Compared to total money spent?
Functioning of the implementation process	Knowledge Diffusion	• The number of workshops and conferences devoted to a specific technology • Network size • Collaborations	• Do you have collaborations of any kind with other firms? • Do you organize, or participate at, official gatherings with regard to micro CHP?
	Guidance of the search	• Specific targets set by governments or industries • Expectations • Involvement of lead users	• What are your expectations (growth potentials) on this technology? • Do you involve lead users in the implementation process? • Are there any specific targets set by the government regarding implementation of HHPs?
	Market formation	• Specific tax regimes for new technologies • Environmental standards that stimulate the development of new sustainable technologies • The number of installed units • Maturity of the market	• How much micro CHPs have you installed? • In what market stage would you say the HHP is in? • On which market segments do you focus? Who are your clients? • What kind of regulations are active in the existing housing sector?
	Resource mobilization	• Subsidies • Outside funding • Human Capital • Complementary assets	• Are the subsidies designed properly concerning the access criteria? • Do you consider it high enough? • Are there any corporate financers? • Do you have enough skilled personnel?
	Creation of legitimacy	• Presence of interest groups • Their lobby actions • Awareness of the technology	• What is the public opinion towards this technology? • How many interest groups lobby for HHP? ○ What are their lobby actions?

Table 2: Operationalization

The operationalization of the seven system functions has given a clear orientation for developing a questionnaire [Appendix B]. It has been drawn up with two types of questions; the first type encompasses the seven system functions, used to describe technical change, the second type of questions highlighted the interaction between the two implementation processes. It was more of a format in which per interview relevant questions for that particular company were added (see table 2). The interviews consisted of an open interview, in which the direction of the interview is not fixed [Baarda and De Goede, 2005]. The open questions allow the interviewer to response to the answers given by the interviewee. This reduces the change of social desired answers. Furthermore, open interviews give detailed insights in complex topics, because it gives the interviewer the opportunity to respond and test the validity of answers given by the interviewee. Furthermore, the interviews have been used to get access to firms' reports and grey literature.

5.2 Data analysis

Data collected through qualitative methods is invariably unstructured and unwieldy [Huberman et al, 2002]. Like in this research, a lot of it was text based, consisting of verbatim transcriptions of interviews. It is up to the researcher to provide some coherence and structure to this data set, while retaining a hold of the original accounts from which it is derived. Therefore, this research has used a roadmap developed by Hekkert et al (2011) for analysing implementation processes using TIS. The manual is a method to do an innovation system analysis in seven steps. Within each step various questions need answering, eventually resulting in a complete description of the TIS. In the first three steps the goal and scope of the TIS are determined. In step 4 and 5 the TIS is described, and step 6 and 7 give an overview of the hampering conditions of the TIS.

To evaluate the interaction between both cases (HHP and micro CHP), a cross-case analysis has been carried out, in which you search for cross-case patterns. There are several pitfalls in this method that need to be dealt with; researchers can leap to conclusions based on limited data, they are overly influenced by the vividness or by more elite respondents, they ignore basic statistical properties, or they sometimes drop disconfirming evidence [Eisenhardt, 1989]. The key to overcome these pitfalls is to look at the data in many divergent ways. Various tactics can be used to do this. Because this research intends to find interaction patterns between the cases, a tactic is used to list and highlight the differences between the cases. When the differences between both cases have been highlighted, it is up to the researcher to investigate whether these differences were caused by the presence of the other competitive technology. During this research, possible interactions were verified during the interviews by searching for agreements by the interviewee on such interactions. For example, when differences in subsidy levels were found the interviewee was asked if he found that these differences resulted in a competitive advantage for one technology. An advantage of this method is that these comparisons should eventually force the investigators to also look for interactions that they did not anticipate [Eisenhardt, 1989]. Furthermore, highlighting any interaction patterns between two emerging TISs contributes to the existing TIS theory, as will be explained in the following section.

5.2.1 Contribution to TIS

First of all, during TIS analysis, the measuring of system functions differs among different studies. This can be devoted to the qualitative nature of the analysis. As described above, almost all the system functions can be measured in multiple ways, or are difficult to measure. Regarding the measurement method, this leads to differences among studies and means that comparisons between several studies on this subject are difficult. The same holds for the value of the measurement. It is, for example, not entirely clear which system functions are most valuable to embark upon technical change. Carlsson and

Stankiewicz (1991) find exchanging information the essential function of networks, while in Hekkert et al (2007) entrepreneurial activity and guidance of the search are seen as important. Therefore, the relevance of such an approach is that it allows you to make that comparison and, to assess the TISs relative of each other.

Secondly, a comparison allows you to investigate whether there is an interaction between both TIS development processes. The emergence of the one technology could have a positive or negative influence on the implementation process of the other. Although motors of innovations show, to some extent, the influence that certain factors, such as overstretched expectations or increasing distrust among selectors, have on the TIS development, these factors are limited to influences from within the structure of the TIS. This research will, to that extend, also contribute to the existing theory, as it will show if a factor from outside the structure of the TIS influences its development.

Thirdly, Suurs et al (2009) have stated in their article; "the technology specific orientation of the TIS analysis brings the risk of evaluating a development as an advocate of that technology". In other words, you might not be objective on the successfulness of the technology. This problem is dealt with when assessing multiple TISs. It helps to develop a broader perspective, which is especially important when it concerns policy makers. The view of multiple perspectives enables them to strengthen their policy decisions as it is based on a variety of options.

Finally, a comparison between two TISs can provide some recommendations on developing basic strategies for analysing implementation processes using TIS. Up till now, a set of tools and instruments that would help practitioners active in analysing their implementation process, and get involved in TIS building, has never been developed [Suurs et al, 2009]. As described above, this is mainly due to the qualitative nature of the analysis and the differences in measurements. A comparison might give an insight in the "best" possible strategy for developing a TIS, or at least improve the current strategy. As long as no consensus is reached on how a TIS should be build up, developing a strategy on analysing implementation processes is useless.
However, to provide insights in this problem you need a strong basis of several cases. Two cases might not be enough.

5.2.1 Historical event analysis

The data from the interviews will be backed up with data found in historical reports, newspapers and professional journals etc. The latter will be mapped by means of the historical event analysis, developed by van de Ven and colleagues [van de Ven et al, 1990; Poole et al, 2000]. It is used to map interactions between system functions and consists basically of retrieving as many events as possible that have taken place in the innovation system using news archives, magazines and reports [Hekkert and Negro, 2009]. By mapping these functions over time, you create insights into the dynamics of the innovation system. Furthermore, it allows you to search for patterns related to technological change. So, this method does not only give insight into how the presence of a function explains the development of the new technology, it also explains how functions interact. As is stated in literature, the interactions between system functions accelerate system change [Hekkert et al, 2007; Hekkert and Negro, 2009].

At the basis of this approach is the event. The events are stored in a database and categorized. Events can be workshops on the technology, the start-up of R&D projects, expressions of expectations about the technology in the press etc. These categories are allocated to one system function by means of an allocation scheme. In such a scheme, events can either have a positive or negative influence on the implementation of the technology. By plotting them in figures, you get a clear overview of the development of the innovation system under investigation over time. This gives a clear picture of which functions are performing well and which are lacking. Furthermore they illustrate which periods show good system functioning and which do not. The final outcome shows how the development of the innovation system has changed over time and the role of the different function in this development.

The juxtaposition of the data from the interviews and the data from the event analysis will be used to highlight any similarity in patterns. This data has been used to answer the research question, and thus find out what interactions can be found between the implementation processes under investigation.

5.3 Quality of the data

In order to assess the quality of the data you need to investigate whether the terms reliability and validity apply to your data and covers the link between data and research. Validity refers to:

"if, what you are observing, identifying or measuring what you say you are" (Bryman, 2008).

Reliability is defined by Joppe (2000) as:

"the extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable".

Embodied within the latter citation is the idea of repeatability of results or observations. When these results stay relatively the same, it indicates a high level of stability, which means the results are repeatable and thus reliable (Golafshani, 2003).
Bryman (2008) has divided each terms into 2 separate terms namely; external reliability and internal reliability, and external validity and internal validity. *External validity*, which is the degree to which a study can be replicated, is a difficult criterion to meet in qualitative research. It is very difficult to freeze any social setting and make it replicable. The same holds for this research, in which a TIS is described. A TIS is constantly evolving over time, any hampering conditions active at this moment might have been dealt with at another moment in time. However, this only holds for the results of hampering conditions at this time, the description of the development of the TIS over time can be replicated because it is history. *The internal reliability*, by which they mean whether, and when there is more than one observer, members of the research team agree on which they see and hear. This research has been conducted by one researcher which means that it cannot be accounted for. *The external validity*, which refers to which findings can be generalized across social settings, is, despite only 9 interviews, in some ways accounted for. Although Bryman (2008) does describe that external validity represents a problem for qualitative researchers because of the tendency to employ case studies and small samples, this is not entirely true for this research. As described earlier, these interviews cover almost the entire sector. However, generalizing any interaction patterns within one cross-case analysis is more difficult. Generalizing the fact if interaction patterns emerge between two competitive technological innovation systems might mean that more cross-case analyses are needed. *The internal validity*, by which they mean whether there is a good match between researchers' observations and the theoretical ideas they develop, has to some extent been corrected for. Two measures can be identified; firstly, the results found in the interviews will be backed up by an event analysis. The event analysis will provide examples for the statement in the results. Secondly, new data, gathered from the one interview, was checked in other interviews. For example, a statement from one interviewee was presented to the other to ask whether they shared that view. In this way a statement was strengthened because it was shared by multiple actors.

6. Results

This section will provide an analysis of the technological innovation systems of the HHP and micro CHP. This means that the structure of the TIS will be evaluated, and the fulfilment of the seven system functions in the HHP and micro CHP sector in the Netherlands will be described. In addition, this section will give a comparison of the Technological Innovation Systems under investigation and shall highlight any interaction patterns between both processes.

6.1 Structure of the TISs

In describing an implementation process of a technology the structure of the TIS is very important. Mapping the structure can provide explanations for the development of a technology. An analysis of the structure can highlight problems and can provide proper measures for guiding the process [Hekkert et al, 2011]. The structure consists of five components that mark the building blocks of a TIS. These components are:

- Politics, policy and institutions
- Research and education
- Industry
- Market
- Supporting organisations

Within each component several actors are involved that play a role in the development, diffusion and use of a technology. Moreover, interaction takes place between these components and its actors.
Another important factor in the structure of the TIS is the stage in which the implementation process is in [Hekkert et al, 2011]. A technology that is in the initial stage of development will show a different TIS structure then when a technology is mature. Furthermore, the theoretical framework has highlighted that within each stage of the process other system functions are important. Therefore, this section will start of by giving a description on the stage of the process, and will continue on the evaluation of the five components of the structure of a TIS. The latter is presented in a figure at the end of the section (Figure 6)

6.1.1 Stage of the technology

The stage a technology is in, depends on the rate of diffusion. Rogers (1962) has shown that the rate of diffusion of a technology over time follows a S-curve (see figure 4).

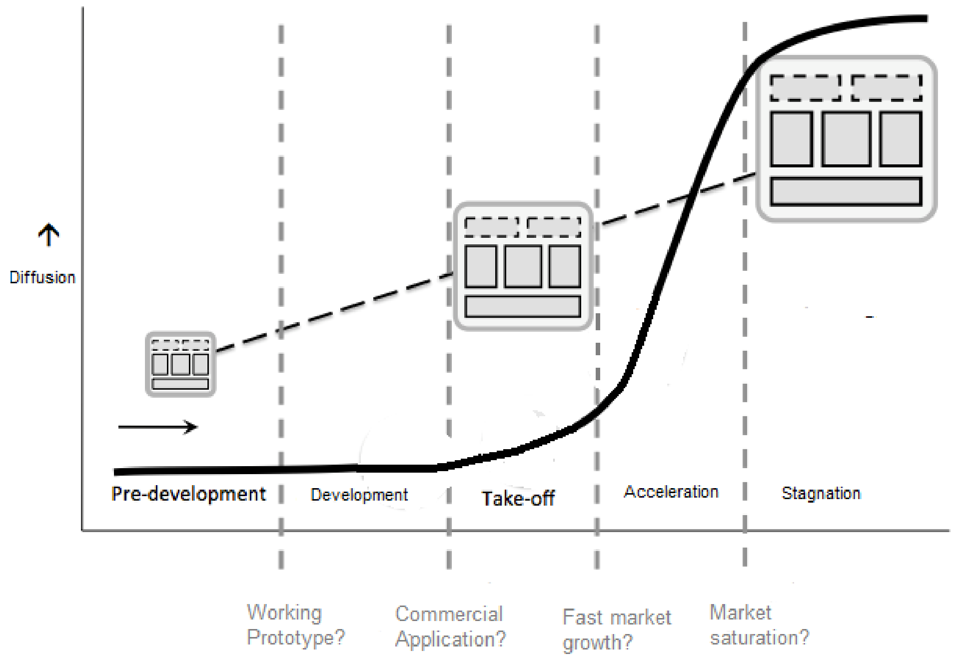

Figure 4: Rate of diffusion over time of a technology

Within this S-curve, Hekkert et al (2011) have defined five stages. To determine the stage of diffusion, the boundaries between the stages are indicated by questions at the bottom of figure 4. For both technologies commercial application is a fact, which means they are both in the take-off stage.

Take off stage means that a product is launched into the market, but large scale production is still lacking. The producers face high production costs and small profit margins, and the technologies need to gain foothold and create a market. Eventually a dominant design could emerge. At that moment product innovation shifts to process innovation and sales numbers can increase.

6.1.2 Structural components

The size of each structural component depends on the number of involved actors. To evaluate which actors are involved, you need to analyse the technological trajectory (see figure 5)

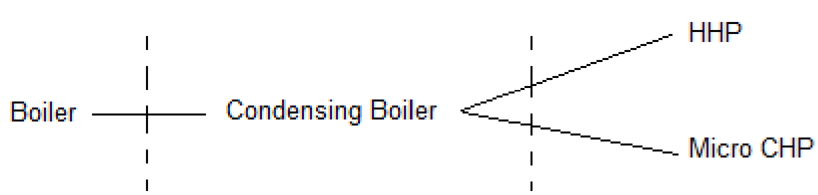

Figure 5: Technological trajectory

Figure 5 distinguishes two relevant chains in the technological trajectory for the evaluation of the *industry* component, namely the condensing boiler, and the HHP and micro CHP (the HHP and micro CHP are both a successor of the condensing boiler and thus in the same chain). The condensing boiler market is dominated by three players; Intergas, Remeha and Nefit. These three account for 80% of the total market, which makes them powerful players in the heating sector [Peter Wagener, DHPA]. Competing

with these actors will be difficult for emerging sustainable technologies because product and process development have led to impressive costs declines. Especially in the Netherlands, where residential heating is build upon an extensive gas infrastructure. This has made the Netherlands a precursor in the development of the condensing boiler, resulting in high cost differences between the embedded technology and the upcoming technologies. At this moment, a condensing boiler costs 1500 Euros, the HHP is 3500 Euros and a micro CHP is 10.000 Euros. This results in long payback periods.
The established firms are also involved in the development of sustainable technologies. Remeha has developed a micro CHP and is the most serious actor in the Netherlands on this market. Nefit has developed a heat pump [Nefit, 2011], and is involved in a collaboration with Inventum on their HHP because they supply the boiler side of the HHP. Whether Intergas is also developing a successor for the condensing boiler is not known [Intergas, 2011].

The HHP market consists of four producers: Itho Daalderop, Inventum, Techneco and AWB (a subsidiary of Vaillant). Sometimes Carrier is also mentioned as a producer of a HHP but they only provide the outside casing of the HHP from Techneco [Carrier, 2011].

When and who first entered the market is difficult to answer because there is no clear consensus about it. The HHP is an idea developed in the late 1990's by Marcel Klootwijk. An actual project on the development was initiated by Senternovem and executed by Gastec [Kleefkens, 2011]. Because Frederik Noordenburg, an employee for Daalderop, had worked for Gastec, Daalderop might have been first. This claim is supported by Peter Wagener. Since 2006, Daalderop has been developing the Combinair (HHP). During the development process they started a coalition with Itho because they had a similar corporate structure and wanted to enhance their knowledge base [Itho Daalderop, 2011].

Shortly after, both Inventum and Techneco entered the market. Techneco had eventually taken up the project from Gastec. Because Gastec did not believe in the successfulness of the HHP, they did not continue on their own project. That is when Essent decided to interfere in the project and brought it to Techneco [Kleefkens, 2011]. Inventum had taken up an own project and was developing a HHP with ventilation air as source [Verbrugge, 2011].

Vaillant was the last to enter the market. They themselves stated that this is mainly due to the fact a large organisation adapts more difficult to a changing environment. Their HHP is not on the market in the Netherlands yet, but said to appear in April 2012. Their subsidiary AWB does have a HHP on the market, called GeniaHybrid. Furthermore Vaillant has been developing a micro CHP unit that should be on the market at the end of 2011 [van den Bergh, 2011].

The first mover for the micro CHP sector was Remeha. Because the micro CHP of Vaillant will not be available till the end of 2011, they are the only one active on the market so far. Some might state that Whispergen had been the first to enter the market. But this micro CHP does not deliver the combination of hot water and space heating, and is not included in the analysis.

Next to producers, the suppliers play a very dominant role in the field of industry, in both sectors. The familiarity with the heat pump technology by producers for air conditioners for example, allows them to produce components against very low costs. Therefore the producers of HHPs are forced to buy the components from their suppliers. This also means that a lot of research has been done by these suppliers. Looking at the number of patents for example, Inventum is the only firm with a patent on this technology, which is not even on the technology but on the suspension structure [Rob Verbrugge, 2011]. The components are simply not patentable. The same applies to the micro CHP because the Stirling engine is an invention dating back to 1816.

The final layer in the structural component of industry is the installation branch. In the Netherlands, this sector installs, maintains and sells heating applications. The latter also makes them an actor in the *market* component. However, novelty of emerging heating applications means they constantly need to expand their knowledge. Therefore, producers and other actors organise professional trainings to get them familiar with the product, which falls under the *Research and education* component. Other actors active within this component are knowledge institutions. Their main activity is conducting research on new applications on the performance and applicability.

Within the structural component of *policy*, both technologies are accommodated in the same policy program called "duurzame warmte" (sustainable heat). This program has been set up by the government in 2008 and aimed at the stimulation of sustainable heat applications like the HHP, micro CHP and solar boilers, through subsidies. However, due to a lack of confidence in the successfulness of these applications, the government cancelled any sequels on these subsidy programs. In an official letter to the chairman of the house of parliament, the minister of economic affairs Verhagen writes on July 4th 2011:

"The subsidy for solar water heaters, heat pumps and micro-CHP was intended as a push for market implementation before the end of 2011 for these technologies, so that after 2011 no subsidies would be needed. These subsidies have not led to the desired expectations. The necessary, and by the sector presented projections for cost reductions through learning curves and economies of scale have failed. Therefore, I have insufficient confidence in continuing the funding of sustainable heating installations for existing housing in 2011" [Ministry of Economic Affairs, 2011].

Other policy measures have come in the form of regulations. Since January 2003 the *Energy Performance of Buildings Directive (EPBD)* is operative in the European Union (EU). The EPBD is a directive that obliges the European member states to five specific activities for improving the energy performance of buildings in the EU [Agentschap NL on EPBD, 2011]:

1. Requirements relating to a general framework for the method of calculating an integrated energy performance of buildings;
2. Minimum requirements for the energy performance of new building;
3. Minimum requirements for existing large building that need major renovation;
4. The energy certification of buildings;
5. Regular inspections of boilers and air conditioning system in buildings, and an assessment of boilers older than 15 years.

This directive has been implemented in various forms in the Netherlands. The second activity has been accommodated in the Energy Performance Certificate (EPC), and has been operative since 1995. The introduction of the energy certifications had been delayed but was implemented in January 2008. This regulation states that the owners, selling or renting their residence, should provide the buyer or tenant with an energy label. The energy label gives insight in the energy efficiency of the house and is designed to stimulate energy saving measures [Rijksoverheid, 2011].

Other forms of stimulation take place in the structural component *"supporting organisations"* (mainly through lobbyist activities). In the micro CHP sector this role has mainly been filled in by Gasterra. They are a Dutch trading company operating on the international market but mostly active in Europe. Their core business is trading in natural gas, but they are furthermore searching for possibilities to use natural gas as efficient as possible. One of these possibilities was micro CHP, which had them decide to get involved in this developing process. Although they have not been active with the actual development of the micro CHP, they have been involved in the stimulation, and lobbying activities for the technology. They have also been stimulating the HHP, though the number of activities stands in poor contrast with

the number of activities within the micro CHP sector [Gasterra, 2011]. Other important lobbyist actors in the micro CHP sector are the three large energy suppliers in the Netherlands, Eneco, Nuon and Essent, and the Smart Power Foundation (SPF) and Cogen, which are interest groups for micro CHP.
The lobbyist activities for the HHP have mainly been taken up by the Dutch Heat Pump Association (DHPA). This interest group aggregated in January 2011 from “Stichting Warmtepomp” (Heat pump foundation) and the “Smart Hybrid Foundation” [Dutch Heat Pump Association, 2011].

The *market* on which both technologies focus is the existing housing sector in the Netherlands. This encompasses housing corporations, companies and the private sector. There is one difference in the application of both technologies though. As explained earlier, the micro CHP is most suitable for buildings consuming a minimum of 2000 m3 gas per year for space heating. The more a household consumes, the more efficient the micro CHP is. The opposite is true for the HHP. A household has to consume as little energy as possible for a HHP to perform as efficient as possible. However, there is still a large amount of households in which both technologies are applicable.

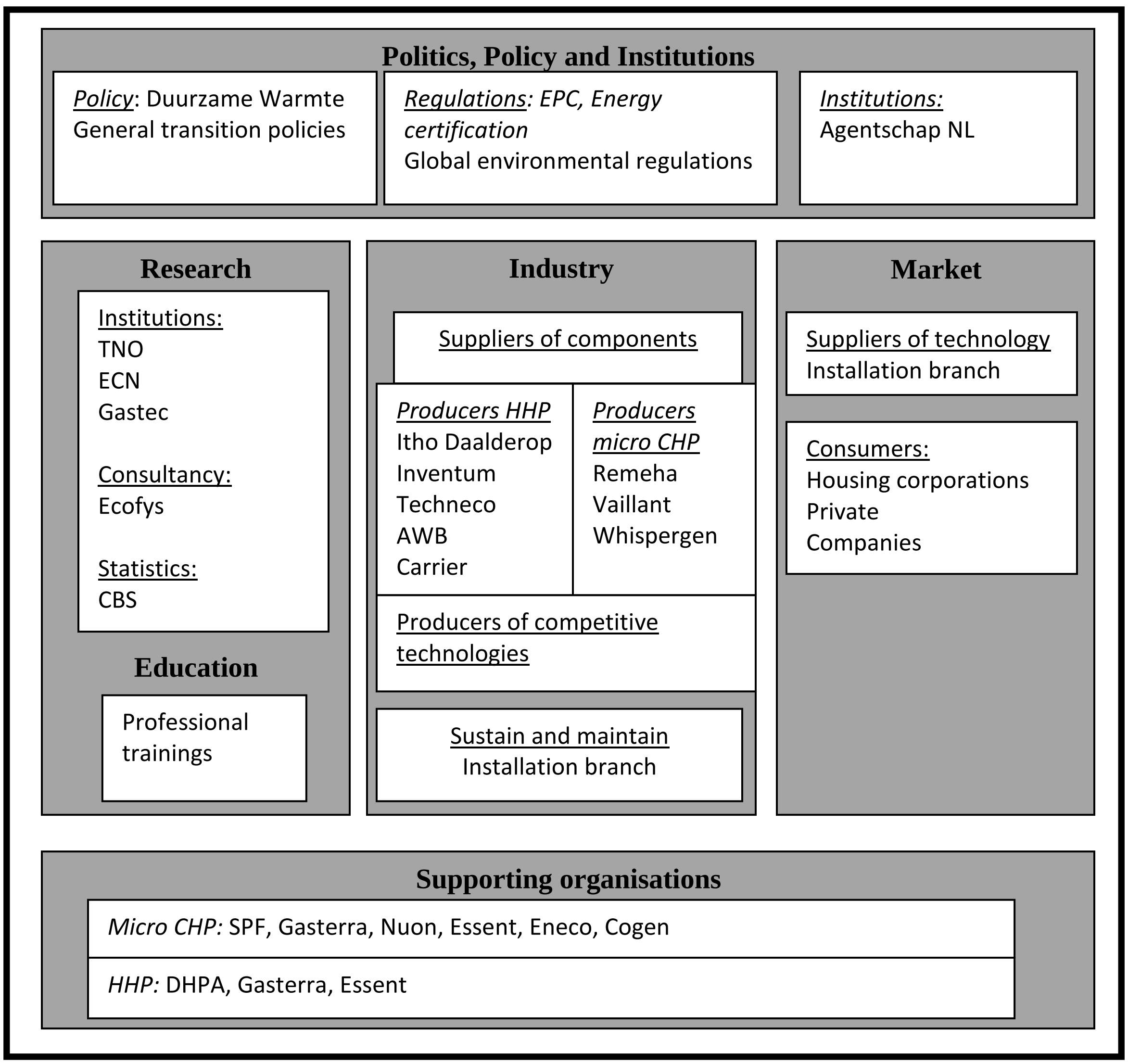

Figure 6: Structure of the TIS of HHP and micro CHP

6.2 Functional analysis of the TIS

To analyse the functioning of the implementation process, the system functions must be elaborated on their functioning over time. This will be done by cutting the implementation process in four different stages described in the theory section; (1) the ***Pre development stage***, (2) the ***development stage***, (3) the ***take-off stage***, and (4) the ***acceleration stage***. Per stage, other system functions play a key role in the functioning of the process. These functions are directly, or indirectly, influenced by the other system functions. The building of the TIS then progresses steadily overtime.
This section is built up on the basis of statements made in the interviews and events collected. However, not every interviewee was willing to have their name attached to statements. This means that the source is not always provided.

6.2.1 Pre-development stage HHP (1998-2006)

During this stage knowledge development (F2) plays a central role because a working prototype needs to emerge. Important supporting system functions during such a process are knowledge diffusion (F3) and resource mobilization (F6). How this evolved for the HHP will be described in the next section.
Since 1995, Novem (eventually Senternovem, now Agentschap NL) has been executing a market introduction program for heat pumps in the Netherlands (F4). This program focused on the large scale implementation of heat pumps in the industry, agricultural sector, non-residential buildings and residential buildings. Therefore Novem initiated Marcel Klootwijk to do a business analysis for the large scale implementation of heat pumps in the residential sector and determine which sort of heat pumps was most promising (F2). This research was the first to analyse the combination of a heat pump with a condensing boiler, then called Ultra Condensing Boiler. The analysis demonstrated some very promising results for the HHP [Klootwijk, 1999]. The promising results were the initiation to start a project on developing a prototype for the HHP. This project was initiated by Senternovem (now Agentschap NL) but was elaborated by Gastec in the late 1990s. The project was described as: "developing a laboratory prototype of a heating application with a 10% to 20% lower primary energy consumption than the condensing boiler, with limited additional investments (F2). Gastec developed the HHP with special simulation programs with the support of the NEO-program of Novem (F3) [Senternovem, 2003]. The HHP was build up from generally available components. Senternovem described the project at that time as ground breaking because of its intelligent control system, and the possible integration of heat exchangers. It had moreover a low price and high efficiency. Gastec realized minimal efficiencies of 127 percent and said that with investments efficiencies of 147 percent could be reached. A remark is that nowadays these efficiencies are a lot higher.

At the end of the process in 2004 the investigators stated that the HHP had to be brought on the market in cooperation with boiler producers, because Gastec was not interested in the further development of the HHP. The idea had been on the drawing board ever since and it was not until 2006 that the first producer Itho Daalderop came into the market (F1). However, they did not continue on the development process of Gastec, but had initiated a parallel developing process in which they elaborated their own idea for a HHP. Shortly after, Techneco did take up the idea of Gastec.

6.2.2 Pre-development stage micro CHP (1996-2005)

The initiation for building a micro CHP installation (F2) came from a consortium of Energy research Centre Netherlands (ECN), Eneco and ATAG in 1996. It had become clear that a free piston Stirling engine would was very applicable for a micro CHP installation because of its reliability and maintenance-free character. Therefore, a coalition (F3) was formed between ECN, Eneco and ATAG under the title "Enatec" to develop a free piston Stirling engine for integration in a micro CHP unit [ECN, 2005]. Initially the developing process went prosperous. For grid connection and the integration of the Stirling engine in the micro CHP unit a patent was acquired. However, problems occurred at the Stirling Technology Company (STC), who developed the Stirling engine. It became clear that a Stirling engine connected to the energy grid could not deliver the desirable amount of electricity (F2) [ECN, 2005]. The Stirling engine without connection to the grid supplied over 1 kW, so the technology had potential. Therefore Enatec decided to continue the development process resulting in a micro CHP unit generating 1 kW when connected to the grid in 2003 (F2).

In 2003 ECN initiated the building of 10 Stirling engines. Together with ATAG they developed a micro CHP unit in which the 10 engines underwent a first field test (F1). Also during that time, a project on cost reduction was initiated (F1). This project was conducted in cooperation with KMWE Precision from Eindhoven (F3), and entailed various activities enhancing knowledge on the micro CHP (F2). For example, transferring from an American measurement system to a European measurement system for example, lead to a cost reduction of 20%. A new design of the micro CHP lead to another cost reduction of 30%. For this purpose, almost all the parts had to be changed by means of materials or production techniques. Furthermore, efficiencies were increased and the weight of the unit was reduced with 15 kg.

At the end of 2003 Rinnai showed interest in cooperating with Enatec (F3). Rinnai is a Japanese producer of gas fired applications for households. They wanted to produce the Stirling engines on a large scale for the Japanese market. For the European market they would function as a supplier for boiler producers. In October 2004, the official agreement between Enatec and Rinnai was signed. This agreement stated that a technological development program (F2) would be initiated that had to lead to market introduction of the micro CHP at the end of 2007.

Rinnai would ensure the investments for the Japanese market but also supports the Dutch budget with a significant share. In 2005, plans for European market introduction were said to be in the last stages of market introduction. This did not apply to the Dutch market however, when the Dutch market would be ready was not yet clear.

It is striking that, although the separate components have been developed long time ago, building a prototype for this technology had taken nine years. Clearly, the combination of integrating a Stirling engine in a micro CHP unit was difficult.

6.2.3 Development stage HHP (2006-2009)

This stage should have as a result the commercialization of the product. That means that entrepreneurial activity (F1) plays a central role. A favourable market environment should be created to get entrepreneurs enthusiastic and willing to invest, hereto guidance of the search (F4) plays a sufficient role. Furthermore, a market needs to emerge (F5); creating niche markets to bring the technology to practical use, or through governmental influence by means of specific tax regimes or by creating awareness within society (F7). Then there are sufficient resources needed to execute such experiments. Think for example about substantive capital or governmental subsidies (F6). Finally, an upcoming technology will always encounter resistance from existing actors or society. Therefore you need to create interest groups to counter such resistance (F7).

The development stage was initiated as soon as the first producers started developing (F1). They each followed their own path of development which resulted in slight product differentiations. Itho Daalderop started developing on integrating the condensing boiler and the air source heat pump in one unit.

Inventum chose to make a heat pump on ventilation air and supply it with a Nefit condensing boiler. Techneco and AWB have a heat pump that is installed next to an existing condensing boiler.
Apart from these differences they all faced similar problems during the development process. To achieve the theoretical energy reductions it was important that the heat pump covered the entire range of capacity. This requires a perfect adjustment of condensing boiler and heat pump. A disadvantage of the condensing boiler as supplementary heating is that it has a relatively high capacity compared to the heat pump (6-7 kW and 4 kW respectively). This relatively high minimum capacity of the condensing boiler has a strong influence on controlling and adjusting the separate components. The basis should be that the heat pump delivers the maximum possible heat contribution. You need to control the fact that the condensing boiler does not deliver supplementary heat when the heat demand can be covered by the heat pump [ter Steeg and Thijssen, 2011].
Another problem occurred in controlling the temperature levels. Due to the relatively high minimum capacity of the condensing boiler, temperatures in the system could raise rather quickly. In that case, the heat pump is less efficient or might even turn off. This means that the producers had to include enough buffer capacity in the system to compensate the peak power of the condensing boiler and eliminate the change of fast raising temperatures (F2).
To realize a system in which condensing boiler and heat pump work properly, the power of the condensing boiler needs to be build up slowly, must be able to run on very little power but still provide enough capacity in the system for the peak loads [ter Steeg and Thijssen, 2011]. Peter Wagener also stated that problems within the sound, weight and unfamiliarity of the installers were a problem. In the Netherlands there are clear regulations on the maximum amount of sound a heating application may produce, which lies on 30 dB in living areas [Verbrugge, 2011]. In the beginning of the process the HHP was still above this. The problem with the installers will be elaborated further on.

To overcome such problems the producers exerted experiments (F1) and set up Research and Development (R&D) projects (F2) to enhance knowledge on the technology. During the interviews became clear that both indicators were present in the process. When the producers were asked if lab tests formed an important aspect of knowledge enhancing in the development process of the HHP they all answered positively. Paul van Dijk from Itho Daalderop answered for example that these experiments happen constantly. “When we develop something new, we first simulate it in the lab”. Rob Verbrugge from Inventum answered by stating they always utilise the lab for developing purposes till their satisfied with the performance. Only then the technology is suitable for field tests. He furthermore stated that they have 16 people in the R&D department. In comparison, Inventum has 110 employees. That R&D was important was shown by the significant amount of money spent on R&D. The producers stated that 30% or even 40% of total costs go to R&D projects. Although you have to remark that these numbers are the total R&D expends, specific numbers on the technology were not present.

When satisfaction from lab tests had occurred, the next step was to implement the technologies in the field. Lab tests can give you a lot of information as, but it can never indicate the actual performance of a HHP in practical use. So when looking at statements made in the interviews, all producers emphasized that, next to lab tests, field test are very important (F1). Therefore all producers carried out various field tests. An example from Itho Daalderop is a pilot project they have done with a public housing corporation from Tiel (F3) [Installatie Totaal, 2009]. The housing corporation wanted to meet the Dutch requirements on energy reduction as fast as possible and found Daalderop in 2006. The project entailed 57 appartments, each equipped with a Combinair. Daalderop was also very involved in the construction of the apartments to ensure high performance of the Combinair. To install the HHP properly, adjustments like good insulations are needed. Inventum initiated a pilot project in cooperation with “Ons Huis” and “Geas Energiewacht” (F3) to install the Ecolution in households of committed residents. The

basis of the project was to minimally jump one label step. The results of the project were promising; in every circumstance one or even two label steps were realized.
These two projects show to some extent the tendency of the producers on the initiation of pilot projects. During the interviews it has become clear that such project are often carried out at friendly users and colleagues, or at least people who share the same affinity with the product as its producers.

To overcome the problem of the unfamiliarity of the installers the producers and the Smart Hybrid Foundation (SHF) organised trainings (F3). On the website of Itho Daalderop for example: *Daalderop offers installers and people interested in the business the opportunity to participate in technological trainings.* On the website of Inventum is stated: *it is very important that our products are installed with the proper knowledge and care at our customers. Therefore we offer technological trainings for free.* Also the SHF organised such trainings. However, this still did not completely cover the problem. The number of participants at these trainings was way to low to reach the entire installation market. This problem remained during the remainder of the process.

The latter has already showed to some extent the involvement of the SHF. To create more awareness for the technology, the producers, in cooperation with Gasterra, founded the branch organization "Smart Hybrid Foundation" (SHF) at the end of 2007 (F7). The idea behind this organization was to create an organization that represents the interests of the producers, and to draw more attention towards the HHP. Up till now they had felt that the existing branch organization for heat pumps in general, "Stichting Warmtepomp" (SW), under emphasized the HHP, due to the large variety in heat pumps. This large variety had also been one of the problems in creating positive awareness among the public (F7). A negative statement on a particular heat pump also affects other types of heat pumps. Therefore the SHF and the producers collaborated in lobbying activities for the HHP in particular (F3). Example of activities had been organising technological trainings to installers and lobby at the government for example.
What has been striking however is that, although the HHP has been around for about 10 years at this point, creating the SHF was the first time attention rose among the technology. Before this time almost no publications are available [Appendix A]. This also meant that there were no real expectations on the technology (F4).

With most technological problems dealt with, the next step in commercialization is creating a favourable environment for investments. This means reducing the risk of investing. This is possible through the issuing of subsidies (F6), creating favourable tax regimes, implementing regulations (F5) or creating positive awareness among the public (F7).
Concerning the subsidies (F6), in 2008, 4 million Euros were issued to the producers of air source heat pumps. However, in a few months the 4 million were gone and no clear policy was made on any continuation of subsidies. All producers (Paul van Dijk, Rob Verbrugge, Gerard van den Bergh etc.) stated that especially the policy around it had been a major bottleneck. The biggest problem was the fickle attitude of the government. The problem was strengthened through the lack of communication. Firms were not able to assume what the government told them, and could certainly not accommodate their policies on these subsidies. Rob Verbrugge emphasized: "*On short term it is nice to have subsidies, but it adds nothing.(...) It is a manner of investing that has no long term vision".* Large financial problems could be a result, as had for example happened to one of the producers. Looking at the affect it has on the entrepreneurial activity, one of the interviewed clearly stated that this ignorance in the policies around subsidies has lead to foreign entrepreneurs not willing to invest in the Netherlands. They needed more security before entering the market.

The same attitude from the government could be seen at the implementation of regulations around the sustainable heat sector (F5). For example, in a report on the policy implications on sustainable heat, Menkveld and Beurskens (2009) already state that the policies were not strict enough, and in general, not designed properly. During the interviews similar statements were given.
In 2008 the first policy measure for the existing housing sector had been implemented (F5). It is obligatory to put an energy label on your house when selling it. This is a similar measure as the labelling of household applications, which means that, depending on the energy consumptions of a building, a certain label from A to G is put on it. In that case, people can see in an overview how much a house consumes. A big remark should be made though; because there are no sanctions for not doing it, there is no compliance with this measure. So although the first measure is a fact, it does not have the desired effect. Therefore it is important that the energy labelling policy should be monitored to make sure it happens (F4). Most of the interviewed backed up this idea and saw potential in this regulation though one was more sceptical: "*It has taken us 3 years let the energy labelling policy get implemented, it will probably take another 3 years to let it be monitored".*

In the new housing estate the Energy Performance Certificate (EPC), a standard that indicates the energy efficiency of a household, has been operative. This started in the Netherlands as an obligatory part in building applications in 1995. Over time this indicator is tightened. Since 2006 a minimal EPC of 0,8 was required, and in January 2011 It has been tightened from 0,8 to 0,6 (0,0 means energy neutral). This has been a major step towards the implementation of more sustainable technologies because an EPC of 0,8 was still manageable with a condensing boiler. To reach the EPC standard of 0,6 you need more sustainable options like the HHP. However, in the new housing estate only 50.000 new heating systems are placed per year [van Dijk, 2011], while in the existing housing market 400.000 boilers are replaced per year. So, although this is a major step in the new housing estate, the existing housing market is still the major energy consumer. Therefore a lot of people, including the interviewed, were still advocating for regulations in the existing housing market.

6.2.4 Development stage micro CHP (2005-2010)
From 2005, the project of Enatec continued on the development of micro CHPs for the European market (F1). On June 6th 2006, another partnership (F3) was created between the actors of Enatec, and the MTS group, Merloni Termo Sanitary S.p.A., to foster the developing process of micro CHP units [ECN, 2006]. The Stirling engines would still be provided by Rinnai. Through the cooperation with the MTS group, the developed Stirling engines could be integrated in the condensing boilers to foster commercialization (F5). Before, the integration had only been realized for knowledge development purposes (F2).

During that time, other boiler producers had started a project to develop a micro CHP for the Dutch market. Remeha was the first and started their development process at the end of 2005. Shortly after followed by Vaillant (F1).

Although the cooperation of Enatec had already dealt with a lot of problems in the pre-developing process of the micro CHP, the problems were not completely dealt with. Realizing a proper functioning Stirling engine turned out to be more complex than anticipated. For example, there were problems with the positioning of the free piston in the Stirling engine. In a free piston engine, the piston his mid stroke position is determined by the balance of forces acting on the piston, in particular flexure and gas pressure forces. This can cause the piston to shift resulting in inevitable piston over strokes. Eventually this problem was dealt with by applying a precisely determined clearance between the piston and cylinder to minimize pressures on the piston to limit piston drift [van der Woude et al, 2006]. On top of this, Remeha had encountered problems during one of their field tests (F1) on the right adjustments of the system, the noise and the weight.

It has become clear that commercializing the micro CHP would turn out to be more difficult than anticipated. The complexity of the process did not only delay market introduction, it also increased the costs of development. Itho Daalderop, one of the HHP producers experienced this first hand. They started developing a micro CHP based on an organic ranking circle (ORC). At the end of 2008 they even started a coalition (F3) with Ceres to enhance the probability of success of the project. However, this could still not prevent them from ending the project because they did not think it would be profitable. The cooperation with Ceres is still there however, and they are still busy with the development of a micro CHP, but this is based on the fuel cell.
Besides Itho Daalderop ending the development process, the partnership of Enatec had also been put to a standstill at the end of 2010. The project had simply become too complex and too costly.

With Itho Daalderop and Enatec ending the development process the list of producers had grown short. Still the number of entrepreneurial experiments to increase knowledge (F2) and foster market introduction (F5) had been relatively high. In the table below you can find some these projects (F1). One must remark that after 2009 more projects have been initiated.

2006 - 2007	Grassland trest with the Whispergen Mark V
2007	Field Test Stirling micro-CHPs from Remeha in cooperation with the foundation "Slim met Gas" (Smart with Gas)
2007 - 2008	Delta test 5 Mark V-units
2008	Gasterra and Essent test the use of HRe-boilers for cooling
2008	Housing Corporation Rentree installs 5 micro-CHPs of Remeha in cooperation with Essent in Deventer
2008	Field test Stirling micro-CHPs of Vaillant in cooperation with "Slim met Gas"
2008	Test micro-CHP based on fuel cell done by Gasterra and Essent
2008 - 2009	Gasterra, Eneco and the community of Ameland place 100 HRe biolers
2009	In Apeldoorn 200 HRe boilers are placed by GasTerra, Liander en Nuon

Table 3: Field tests with micro CHP till 2009

As the table shows, Gasterra is frequently involved in the implementation process of micro CHP. Although they never took active part in the developing of the technology, with their background as a trader in gas they played a significant part in the stimulation and lobbying activities for this technology. Their main role in the development of the micro CHP has been analysing the technology and trying to get foreign and domestic producers enthusiastic in investing in the market (F7). Furthermore they fostered the implementation process through funding (F6).

Another significant event that happened during this stage of the implementation process has been the founding of the interest group Smart Power Foundation (SPF) in 2006 (F7). This interest group aims at large scale implementation of micro CHP. They have mainly been involved in initiating and stimulating

technological developments, dealt with regulations and applied for subsidies [Smart Power Foundation, 2011]. Within the latter, the SPF has had a significant contribution.
In 2008, the government had decided on constituting a policy project called “Duurzame Warmte”, in which subsidies for sustainable heat applications in the existing housing sector would be included [Rijksoverheid, 2008]. By that time the SPF published an article in which they stated that 90 million Euros would be needed to have 1 million micro CHPs installed by 2020 [Appendix]. In a response, the minister of environment van der Hoeven promised 10 million Euros in August of 2008 [Slim met gas, 2008]. However, in the policy project of “duurzame warmte” only 4 million were included, which meant 4000 Euros per unit. What were to happen with the other six million was not clear yet. It was said that the micro CHP first had to proof itself.
The issuing of subsidies had been a major breakthrough for commercialization of the micro CHP. The unexpected problems with the technology, resulting in ever postponing the commercialization of the product had namely cost a lot of money. Subsidies are also important for creating a favourable environment for investment (F5), which might result into more investors entering the market. On top of the subsidies the government had also funded the process of the micro CHP by other means. Onno Kleefkens namely stated that the government had funded the implementation process with many millions.

A field in which the government had lacked policy measures was implementation of regulations stimulating sustainable technologies (F5). Because both the HHP and the micro CHP aim at the existing housing market, the same lack of regulations applied here. So although this is already described in the HHP section, one small remark has to be made here. The micro CHP is most applicable in households with a gas consumption of 2000 m3 or more, households that can especially be found in the existing housing sector. This is due to the fact that the micro CHP recovers itself with the production of electricity. Because one kWh electricity is more expensive than the gas required to produce that one kWh, the micro CHP benefits from a high electricity productions. So without a market in the new housing estate, and only a temporary policy on subsidies as a driver for implementing sustainable technologies in the existing housing sector, the micro CHP sector had a problem. Due to this upcoming problem, *“HRe in versnelling”* (HRe in acceleration) was founded in 2009 (F7). Under this heading, a support team of several actors (Gasterra, SPF, Aedes, Energy Matters, supportteam Energietransitie) acts as a catalyst between the producers and the housing corporations [HReinversnelling, 2011]. Because the micro CHP is simply too expensive, the housing corporations could not invest in several units by themselves. The support team brought them together so they could place orders at Remeha collectively (F3) [Overdiep, 2011], and lower the costs per unit.

6.2.5 Take-off stage HHP (2009-now)
This stage starts with the commercialization of the product. A lot of factors that were important during the development stage are also important here. That means that entrepreneurial activity (F1) still plays a central role. A difference though is that the interest groups play a more important role in breaking through the resistance from society and embedded technologies.

During the development stage of the implementation process, some major problems had occurred but the producers realized market introduction in 2009. Soon became clear that the SHF had not functioned as they had liked (F7). Having two interest groups lead to problems. This is remarkable because during the foundation of the SHF the producers were certain another interest group was needed. Still, the aggregation of the SHF and SW was initiated, and the Dutch Heat Pump Association (DHPA) was founded in January 2011. It did indeed have several advantages; Firstly, consumers do not think in various types of heat pumps but in heat pumps in general, one interest group can deliver a clearer statements to the public (F7). Secondly, they were taken more seriously within the government (F4). Thirdly, an interest group aims in a certain direction, which means that two separate groups can contradict each other. Finally, an interest group has to be an advocate of the technology it represents, and shall always encourage the use of that technology. As a result, an interest group will recommend an unsuitable heat pump in certain situations. Investors will be misinformed (F3) on which technology to use. DHPA can now evaluate the situation and advice on which application is best, in that particular situation [Wagener, 2011].

After the aggregation of both interest groups into the DHPA (F7), one of their most important tasks has been to continue with the problem of the lack of knowledge at the installers (F2). As has become clear in the previous stage, not enough installers participated at the trainings. The DHPA intensified their efforts by approaching installers and get them to participate in trainings. The importance of knowledge within the installation branch (F2) can best be illustrated by the number of negative publicity (F4). A lot of negative articles have been published on the fact that heat pumps do not work properly, and do not live up to the expectations (F4). A good example of such an article was published in Trouw, a Dutch newspaper, on June 20th. In this article they begin by stating that the technology is not efficient, while some further reading reveals that the situation in which it was implemented was not at all practical for the heat pump. They building were far from well insulated, leading to high heat transmission losses. In such a situation, a heat pump consumes needless extra energy to keep the house warm. In addition, an investigation by the independent research institute Liandon (2010) showed that the peak load of the heat pumps was provided by an electrical element also leading to high electricity consumption. Such an element should only be used during power failures. This project highlights that heat pumps are still implemented in unsuitable locations and that the installers cannot adjust them properly.

By that time it had become clear that no sequel for subsidy programs would be issued in the sustainable heating sector (F6). This has been a major setback in the implementation process. Subsidies reduce the investment costs and, with that, reduce the payback period. Because the regulations in the existing housing sector are not observed (F5), there is a lack of incentives to invest in a HHP. The cost difference with a conventional HR boiler is simply too great. Marcel Klootwijk stated that society will not even consider new sustainable technologies with such cost differences. It is therefore very important that regulations are tightened. In the mean time, the producers were unable to increase sales in the existing housing sector, which forced them to focus on other market segments. Due to the EPC regulations, the new housing estate is one of these segments. Gerard van den Bergh stated for example: *The large potential lies in the existing housing sector, but the introduction shall run via the new housing estate.* Another market segment is the housing corporations in the existing housing market. A growing interest for sustainable technologies exists because the interest groups of housing corporations have agreed with the government that before 2020 their houses should be at least label B, and if that is too difficult, make at least two label steps [Verbrugge, 2011].

In summary you could say that the HHP still faces some major bottlenecks for implementation. Although you do get the feeling these are being addressed by both the producers and the DHPA, large scale implementation remains difficult.

6.2.6 Take-off stage micro CHP (2010-now)

Commercialization had been a fact for the micro CHP in 2010 but the technology had certainly not taken off. Therefore the expectations on the successfulness of this technology had been reduced drastically (F4). Up till now the success of the micro CHP was mainly build on high expectations created by major lobbyist capabilities (F7). The major delay in commercialization, 2010 instead of 2007, has had its affects on the entire implementation process and also influenced the view of the government. Like for the HHP, the micro CHP subsidies were also not continued. The previous subsidies had not led to the desired learning curves and cost reductions (F6). On top of that, the government cancelled the promised 6 million (F4). However, what the government might not have realized is that with 4000 Euros per micro CHP, only 1000 units can be subsidized. This is hardly enough to realize any cost reductions. This opinion is shared by the Paul Gelderloos; who stated it was way too little for large scale market implementation.

The biggest problem the micro CHP sector now faces is the large cost difference between the condensing boiler and the micro CHP, because without subsidies the cost difference is around 8500 Euros. No actor is willing to invest that much more [Klootwijk, 2011]. Therefore Paul Gelderloos stated that subsidies are really needed to get this product past the first bump of introduction. This might be recorded as the major bottleneck for implementing the micro CHP at this moment. This might have been foreseen by other entrepreneurs active in the earlier stages of the process, who did not want to base their returns on subsidies. As a result, there is still a lack of entrepreneurial activity (F1).

Facing such a major bottleneck might be the reason that Paul Gelderloos from Remeha stated that the regulation of house labelling is not going to foster their implementation process. More drastic regulations are needed to enhance the chance of market expansion. As mentioned earlier, this opinion is shared by Marcel Klootwijk. An example for other measures might for example be to increase the taxes on fossil fuels (F5). *"People should feel that they are using too much energy"*. This might be the only way to reduce the payback period of the micro CHP. Hans Overdiep stated that this should be reduced to 5 to 7 years in order for the technology to take a lift.

Another focus for implementation of the micro CHP might lie in "HRe in versnelling" (F7), because just now they realized a first project in the housing corporations (F1). During 2011 a series of 300 units will be installed among various housing corporations [HReinversnelling, 2011]. "HRe in vesnelling" enable the housing corporations to jointly place an order and reduce costs.

In summary, one cannot deny the cost of the technology is still the major bottleneck for implementation. With high cost, and no other measures that reduce payback periods, the micro CHP faces large problems. One might state that high production costs, combined with a lack of regulations (F5) and resources (F6) has reduced the entrepreneurial activity (F1) and expectations on the product (F4).

You could state there are some major bottlenecks for implementation in both processes. To give an overview, all the system functions are mapped in table 4, below. Per function a score has been given from - - to ++ (meaning very bad and very good respectively). This has been an average of the scores per indicator. The scores are explained in the last column.

Function	*Score*	*Reason*
Entrepreneurial activity HHP	+	• Four entrepreneurs active on the market so far, still could have been more. Since the idea has been presented to the producers five years ago, no new entrants in the market. Is said that more entrepreneurs are in development however (Vaillant for example) • Numerous set of field tests and lab tests done with the technology.
Entrepreneurial activity micro CHP	0	• Only one entrepreneur active on the market at this moment. Therefore there is no competition. Competition that is needed to enhance cost reductions of a product. During the development process one can only state that more producers have cancelled the development, instead that more have entered. One must state however that this is very much influenced by the lack of creating a favourable environment for investment (F6, F5, F4). • On the other hand a lot of field tests and lab tests have been executed with the product by various actors.
Knowledge development HHP	0	• No real knowledge development has taken place because all components were known. The knowledge that needed to be generated was on adjustments and this has been gathered through sufficient enough lab tests. For example, only one producer has a patent, and that is on the suspension of the product. • Most producers stated that R&D funding was high, but could not give specific numbers on what part of those funding went to the hybrid heat pump. Typical percentages of R&D, compared to total money spent, was 30%
Knowledge development micro CHP	-	• The same holds for micro CHP as for the HHP when looking at the knowledge about the components. However, problems with weight noise and specifications led to difficulties and a delay of market introduction. • Producers could not give a specific number of R&D funding, but stated that a significant amount of total budget goes to R&D, and to the development of the micro CHP.
Knowledge Diffusion HHP	-	• No real collaborations between the producers, except that they are collectively joint in the DHPA to foster lobby actions (F7). • Knowledge does not flow adequately through the network. A major bottleneck is that installers do not possess sufficient enough knowledge to adjust and install a HHP • On the other hand, a lot of conferences and meetings are organized to enhance the degree of knowledge diffusion. Furthermore trainings have been set up to increase the knowledge of installers.
Knowledge Diffusion micro CHP	+	• Numerous collaborations: (1) Joint venture during the development process under the heading Enatec. (2) Joint in a interest group SPF, (3) Itho Daalderop coalition with Ceres in developing ORC, (3) "HRe in versnelling" in which a coalition of several actors form a support group bringing together various housing corporations • Numerous conferences, meetings and gatherings to foster knowledge diffusion
Guidance of the Search HHP	-	• No clear communication from government what their policy on sustainable heat would be. Eventually only temporary measures without the guarantee of future funding. • Number of negative published articles exceeds the number of positive articles. This has reduced the expectations on the technology. Although these articles are mainly on heat pumps in general, it affects every heat pump.
Guidance of the Search micro CHP	+	• A lot of positive awareness among the public concerning the micro CHP. A couple of established companies lobbying for this technology (F7), raising expectations. Only positive publications could be found • Although also government enthusiastic about the technology because of its gaseous application, also the micro CHP producers were detrimentally influenced by the lack of communication on policies
Market Formation HHP	-	• Lack of installed HHPs • Only labeling regulations in the existing housing sector, and that is not being observed • Benefit from the strict regulations in the new housing estate, as the HHP is also applicable there.

Market Formation micro CHP	- -	• Lack of installed micro CHPs • Only labeling regulations in the existing housing sector, and that is not being observed. Also, more drastic regulations are needed to give the micro CHP implementation a boost. • Can not really benefit from regulations in the new housing estate
Resource Mobilization HHP	- -	• Lack of funding from corporate actors • Subsidies for air/water heat pumps gone within 3 months
Resource Mobilization micro CHP	-	• Gasterra as a major funder • Subsidies were too low to foster market expansion. Now real problem as micro CHP can not expand without subsidies
Creation of Legitimacy HHP	+	• Interest group DHPA, aggregated from SHF and SW • A lot of various activities (Organize meeting and training (F3), ensure funding (F6)) with creating awareness and lobbying as a core activity
Creation of Legitimacy micro CHP	+ +	• Interest groups SPF and energy matters • Also established corporations like Gasterra and Dutch energy suppliers with a lot of power to lobby. • Numerous activities in lobbyist actions (organize meetings), and ensure funding.

Table 4: Overview of scores per system function (scale ++/0/--)

6.3 The interaction

The description of both implementation processes has enlightened some driving factors and bottlenecks in both implementation processes. By performing a cross-case analysis, differences and similarities should emerge that can highlight interaction patterns. It is plausible to think that when functional differences occur between two competing technologies, it can create a competitive advantage for one technology. This means that an interaction is present.

The main goal in this section is to indicate in what way the performance of the seven system functions differs from a conventional TIS analysis when taking a competitive technology into account. The interaction patterns will be highlighted on the basis of the different stages in the implementation process. During the pre-development stage no clear interactions were found.

6.3.1 Development stage

These scores have again been evaluated, in which the degree of differentiation will highlight the influence between the implementation processes (see table 5 below). The most influential difference can be found in the degree of lobby strength (F7). It is not that the number of interest groups or their lobby actions differs; the difference lies in the size and name of companies lobbying for the two technologies. For example, on the one hand, you have the producers of the HHP with an average number of employees of 180, and on the other hand you have Remeha, who has 6000 employees all across Europe. However, a major part in the lobby differences can be attributed to Gasterra. Although Gasterra was also involved in the implementation process of the HHP, they themselves stated that this stands in poor contrast with what they have done in the micro CHP sector. The reason was that the micro CHP fits more into their vision of being as efficient as possible with natural gas.

The fact that it did indeed influence the lobby capabilities of the HHP sector was illustrated by the statements made by the HHP producers. When they were asked if their sector was missing such an actor that can exert power in the heating sector, they all answered positively. For example, Rob Verbrugge from Inventum stated: *With the large lobbying activities and promotional work the micro CHP sector has done, they have reached more actors than we could. We cannot compete with such lobby strength.*

The difference in lobby strength led to a competitive advantage for micro CHP. This can be illustrated in various activities in which Gasterra has also been involved. First of all, the extraction of subsidies (F6) is very much based on your lobbying capabilities at the government (F7); you need to make yourself noticeable in order to get a fair share of subsidy [Wagener, 2011]. That means that stronger lobby actions can result in a bigger share of subsidies. In the beginning of the process such an unequal distribution of subsidies could also be seen in the heating sector. The involvement of Gasterra was shown by the fact that minister van der Hoeven personally handed them 10 million Euros. The difference in resource mobilization was strengthened by the differences in additional funders. Mainly Gasterra fostered the implementation process through funding of various projects with micro CHPs (F6), but also the government had put more money into the micro CHP project than in the HHP project. Onno Kleefkens stated in the interview: *"It is striking that the government puts many millions in the development process of micro CHP, while only half a million went to the development process of the HHP".* Rob Verbrugge from Inventum added: *I do not know if the governmental sees more potential in the micro CHP, I do know that they receive more money.* Such differences can have market distortion as a result. When one technology favours a significant amount of extra subsidy, it can create a competitive advantage over its competition. Secondly, lobby actions create more attention and generate higher expectations (F4), which can clearly be illustrated by the two graphs on guidance of the search [Appendix A]. Only positive articles could be found on micro CHP, in which a lot of background information came from companies like Gasterra.

Producers from the HHP sector have blamed the government of mainly focusing their attention towards the micro CHP (F4). Due to the fact that the Netherlands has an intensive gas infrastructure, it is claimed that the government would favour the micro CHP for economic reasons. Rob Verbrugge namely stated: *Everybody in the government knows about micro CHP, but not everybody knows about the HHP. This is mainly due to the lobby strength of micro CHP.(...)When the government had really investigated the potentials for both technologies, it is ridiculous that such differences in subsidies exist between these technologies.*

6.3.2 Take-off stage

In the previous stage a competitive advantage for the micro CHP had emerged through differences in lobby strength (F7), higher expectations (F4) and resource mobilization (F6). But a chain of events resulted in a shift in competitive advantage towards the HHP. The chain of events was initiated by the fact that after commercialization the micro CHP still cost 10.000 Euros. The producers had not anticipated that the development process would be this costly. On the other hand, it was still assumed that another 6 million Euros subsidy would be issued. When the decision was made to cancel a sequel for the subsidy program, the competitive advantage for micro CHP disappeared. Paul Gelderloos from Remeha emphasized: *"On the long term a technology has to be economically attractive without subsidies, but for the first bump of market introduction we do need them".* That the competitive advantage had disappeared was strengthened by the lack of regulations in the existing housing sector. A micro CHP is in particular applicable in buildings with higher energy consumption, so that more electricity is produced. Newly build houses are too well insulated for a micro CHP to be efficient in cost return. This means that the focus for implementation remains on the existing housing sector, where no real incentives exist for investing in expensive sustainable technologies.

The investment costs for the HHP are much lower, around 3500 Euros for the consumer. Although Marcel Klootwijk has stated this is still too much compared to the condensing boiler, another advantage for the HHP lies in the fact it is better applicable in the new housing estate. Due to the EPC regulations this market segments shows more incentives to invest in sustainable technologies.

6.3.3 Cooperation

The competitive advantage for the HHP has resulted from the fact that they are less affected by the lack of subsidies (F6) and the lack of regulations (F5). This does not mean that it really enhanced diffusion of this technology. But because both technologies face similar hampering factors the interaction could focus more on a cooperation between the technologies. They could for example combine their lobby actions (F7) and pressure the government to realize the implementation of new policies on reducing energy consumption. Furthermore, the installation of either technology on one place can overload the electricity grid locally during peak loads [Kok, 2010]. A combination between the HHP and micro CHP could overcome this problem. But this may only be achieved through an intelligent distribution network called a smart grid. There have been examples of smart grids used as demonstration projects in which the HHP and micro CHP are combined (F1). One of these projects has been conducted in the Netherlands. The project consisted of 25 households where the one half had been equipped with a micro CHP, and the other half had been equipped with a HHP. These houses have all been connected to form a virtual power plant. The hybrid heat pumps and the micro CHP units had been connected to a hot water storage system. Smart regulators determine whether the HHP or the micro CHP provides heat to the storage system. When the electricity price is lower, through additional revenue from solar panels for example, the HHP provides extra heat. When electricity price is high, the micro CHP delivers the heat, and additionally generates electricity [PowerMatchingCty, 2011]. With the right adjustments, combining both technologies allows for an optimal usage of both technologies. A small remark is that these systems have not yet been commercialized, but could enhance the diffusion of both technologies in the future.

In table 5 on the next page an overview of the interaction patterns is given. The arrows in the development stage indicate a relation between the interactions; the interaction in creation of legitimacy led to an interaction in resource mobilization and, in an interaction in guidance of the search.

Interaction patterns	**Why**	**Reason**
development stage → Favouring micro CHP		
Creation of legitimacy (F7) ↓	• Major differences in lobby strength	• Gasterra major lobbyist for micro CHP. Did also lobbying activity for HHP but stands in poor contrast. • Remeha is a large and well established company in the heating sector. They have more resources than the companies in the HHP sector.
Lead to an interaction in Resource mobilization (F6) ↓	• Difference in the issued subsidies • Differences in corporate funding	• Micro CHP was promised 10 million, air source heat pumps only 4 million • Gasterra has been a major funder of the micro CHP. Such an actor was not present in the HHP sector • Government funded the micro CHP process with many millions while they only put half a million in the HHP
Lead to an interaction in guidance of the search (F4)	• Differences in the expectations	• A lot of positive publications on the micro CHP while the heat pumps sector also showed some negative publications
Take-off stage → Favouring HHP		
Resource mobilization (F6)	• No continuation on the subsidy programs	• Micro CHP costs 10.000 Euros while HHP only 3500 Euros so they are most affected by the ending of subsidy program. Micro CHP really needs subsidies to get past first bump of introduction
Market formation (F5)	• No stringent regulations in existing housing sector • EPC regulation in new housing estate	• Micro CHP best applicable in existing housing sector, due to lack of regulations there is a lack of incentives to invest in micro CHP • HHP is also applicable in the new housing estate. There regulations demand for more sustainable options. This means that there are more incentives to invest in HHP.
Cooperation		
market formation (F5) and Resource mobilization (F6)	• Face similar hampering factors → lack of subsidies and lack of regulations in the existing housing sector	• Could combine their lobby actions to overcome both these problems. In this way they might persuade the government to continue subsidies or implement more stringent regulations, or might make it easier to find corporate funders.
Enterpreneurial Activity (F1)	• the installation of either technology can overload the electricity grid during peak loads	• Combining them in smart grids could overcome this problem.

Table 5: The interaction patterns (the arrows indicate a relation between the interactions)

7. Discussion

The cases of HHP and micro CHP are used to highlight interactions between two competing TIS trajectories. Differences obtained through a cross-case analysis had to yield these interactions. The method section already showed that these differences can only highlight an interaction when the two technologies are competing for the same market. Although the two are seen as competing technologies, their possible market application differs. The reason lies in the differences in efficiency in various applications. Because the micro CHP has its high efficiency through its local electricity production, it is in particular favourable in buildings with higher energy (gas) consumption. The opposite is true for the HHP that has its highest efficiency in good insulated, low energy label houses. This means that the technologies might not actually be competing for the same market. Functional differences between technologies that are not competing for the same market might highlight differences in performance, but do not highlight interaction patterns.

A second point of discussion is the number of interviews. Three interviews have been conducted within the micro CHP sector, compared to six interviews in the HHP sector. Especially the interviews with the producers do not yield entirely objective answers. Their answers shall always be in the interest of their technology. A difference in the number of interviews creates more arguments in favour of one technology and results in data indifference. This could make this research an advocate for the technology with most respondents. Therefore it is important to remain as objective as possible.

Another point of discussion is that this research faced some gaps in the data. The novelty of the technologies meant that proper data could not always be found, especially in the earlier stages of the process. The project by Gastec, initiating the pre-development process of the HHP is an example. It had been too long ago for the interviewed to give detailed information on that matter, and there was a lack of published literature. Small amounts of data that were found referred to the site of Gastec, which no longer exists. Gastec was taken over by Kiwa in 2005 [energie.nl, 2005], and the site of Kiwa does not mention the project. Such problems might have resulted in an incomplete dataset in some places.

The usage of TIS as a theory to describe technological change is a fourth point of discussion. As Bergek et al (2008) point out in their article: *"We are still at an early stage in our understanding of how TISs emerge and develop and we need to learn a lot more about methods such as indicators and, most importantly, about how to assess functionality".* This means that there is still no consensus on how to properly operationalize the system functions. Although Bergek et al (2008) and Hekkert et al (2009) do present such schemes; they are by no means finished products. When the indicators used do not represent the system functions they tend to address, this research could have made wrong claims.

A final point of discussion is the difficulty in creating boundaries on which events to include in the event analysis for the HHP and which to exclude. This had various reasons. First of all, the large variety in heat pumps made it difficult to select all relevant events. Secondly, there is no common name for the hybrid heat pump which makes it difficult to put in relevant key words. Finally, because Society does not think in a variety of heat pumps, but in heat pumps in general, general events on heat pumps also affect the HHP. This means that they should also be included in the analysis.

8. Conclusion

In section one the following research question has been phrased: *How do the implementation processes of two emerging competitive technologies in the Netherlands, the hybrid heat pump and micro CHP, interact?* Also a number of sub questions have been developed. To answer these questions this research evaluated the implementation processes of the HHP and micro CHP to indicate any interaction patterns between their system functions. These will again be highlighted in this section.

The main driving factor in the HHP sector has been the entrepreneurial activity (F1). Entrepreneurs have been the driving force behind numerous significant events. First of all, the entrepreneurs have dealt with the technological difficulties of combining a heat pump with a condensing boiler (F2). Through testing the technology in lab tests and field tests they have eliminated technological flaws in the HHP. Secondly, the entrepreneurs have initiated the foundation of the SHF and increased awareness for the technology (F7). Finally they have kept a broad focus on various market segments to enhance implementation of the HHP (F1). The private existing housing sector lacks incentives for investments which meant they had to focus on other market segments to enhance implementation. Therefore the entrepreneurs have sought for collaborations (F3) with existing housing corporations. The applicability of the HHP in the new housing estate, combined with the EPC regulations (F5) in this sector has also enhanced implementation.

The HHP is still not at the break of large scale implementation. There are some major factors hampering the implementation process that must be addressed in order to enhance implementation. One major bottleneck has been the lack of involvement of the Dutch government. This has been reflecting upon several events. First of all, the subsidy program was not designed properly. Subsidy levels were too low and it lacked long term vision (F6). Secondly, the government lacked the ability to make decision on policy strategies, and lacked communicating this with the actors in the field (F4). For example, it has taken them almost a year to decide that subsidy programs were not continued. During this period there was great ignorance among the producers. Thirdly, there has been a Lack of regulations in the existing housing sector. The only policy measure active is energy labelling (F5), and this is not being observed (F4). These three events combined have decreased incentives for investing in the HHP market (F1).
The government is not eager to stimulate any form of sustainable development during economic crisis. That makes these problems difficult to overcome. The actors can merely increase lobby activities and convince the government of the importance of the HHP (F7). The DHPA is for example busy to realize more stringent supervision of the energy labelling policy. An action undertaken by the producers is to shift the focus from the existing housing sector to the new housing estate, where the EPC regulation is operative.

Another bottleneck in the implementation process was the lack of knowledge in the installation branch, resulting from a lack in knowledge diffusion (F3). Not many installers are familiar with how to install and maintain a HHP. This means that fast implementation holds off. It has furthermore led to negative publications (F4), of which a project in Zutphen is an example. Therefore the DHPA and the producers organise trainings to enhance knowledge within the installation branch.

Finally, there has been a lack of awareness about the technology among society, especially in the earlier stages of the process (Pre-development and development).

The main driving forces in the implementation process of the micro CHP have been guidance of the search (F4) and creation of legitimacy (F7). Especially in the beginning of the process, the micro CHP technology experienced a lot of support, mainly from Gasterra and the government. Gasterra has supported through a lot of funding (F6), set up various field tests with the technology (F1) and was involved in lobbying activities, increasing awareness for the technology (F7). The latter was best illustrated by the fact that Gasterra was frequently named in articles as a reference for micro CHP. This led to an increase in expectations for the technology. The government has been less involved, but did support through funding (F6) and through increasing expectations on the technology (F4). Furthermore the presence of the interest group SPF (F7) had also led to subsidy programs and an increase of awareness.

In the later stages of the implementation process the micro CHP began to lose support and expectations on the technology decreased (F4). There are several hampering factors that have caused this.
The first major bottleneck was encountered during the developing process (F2). Problems with grid connection, performance, weight and adjustments delayed the process, and commercialization was postponed (F5). The delay in the developing process increased costs and decreased the willingness to invest, and entrepreneurs that had started the developing were forced to stop the process (F1). Eventually these problems were overcome by exerting numerous experiments (F1) with the technology. Entrepreneurs, Gasterra, Essent etc have carried out various field and lab tests that increased knowledge development (F2).
Secondly, the micro CHP shared the same bottleneck as the HHP on a lack of subsidies (F6). However, various events strengthened this hampering factor for the micro CHP. First of all, the four million Euros issued were way to low to realize a lift in market introduction. Secondly, the government had misinformed the market by promising 10 million Euros, but issuing only 4 million Euros (F4). Because the other 6 million were withdrawn in 2011, the high costs left the entrepreneurs with a technology they cannot sell.
The latter is also a result from the fact that there has been a lack of regulations (F5). This is a difficult problem to deal with because the micro CHP is not applicable in the new housing estate, and cannot benefit from its EPC regulations. Therefore the entrepreneurs focus on housing corporations and have cofounded "HRe in versnelling" with Gasterra (F3). By bringing housing corporations together they can jointly place an order at Remeha and reduce the costs of investments. Furthermore, lobbyist activities (F7) should persuade more actors to invest in the process.

This research has intended to investigate how two emerging TIS trajectories interact. Up till now, competing TIS trajectories were seen as part of the environment instead of including them in the analysis. However, this research has shown that the fulfilment of the system functions is certainly dependent of the presence of a competitive technology, at least for the HHP and micro CHP case. Differences in the fulfilment of the system functions could for example create a competitive advantage for one technology hampering the implementation process of the other.
In the development stage the difference in lobby strength (F7) showed that a competitive technology can overshadow lobbying activities of a technology under investigation. As a result, the lobbying activity for the HHP did not have the desired impact. Had the competitive technology been excluded from the analysis, the scoring for creation of legitimacy of the HHP would be higher because you would not have considered the fact that these lobbying activities were overshadowed by the micro CHP lobbying activities. Moreover, this led to higher expectations (F4) and more awareness for the micro CHP. When comparing how both technologies are depicted in the media, it is noticeable that the expectations on the micro CHP are more positive [Appendix A]. It furthermore led to more funding for the micro CHP (F6). Gasterra and the government have funded the micro CHP with a significantly higher amount than the

HHP. This created a competitive advantage for the micro CHP. The emergence of a competitive advantage is the reason that the scores for the system functions of the HHP chances. Although they did receive financial resources, these stood in poor contrast to the funds put into the micro CHP development.

However, a major turning point has been the discontinuation of the subsidy programs (F6). Due to the high costs per micro CHP, the sector is more dependant of funding. A lack of subsidies, combined with the lack of regulations (F5) in the existing housing sector, has put the implementation process at a standstill. While the HHP can benefit from the more stringent regulations in the new housing estate, the micro CHP cannot. That means that a competitive advantage emerged for the HHP. This does not mean that the HHP has taken a lift, but they are a little further in the implementation process. Also the HHP is, with 3500 Euros, too expensive compared to the condensing boiler. Therefore a measure to foster implementation for both technologies might be in combining forces. The applicability of a combination of the technologies is that the micro CHP produces electricity while the HHP requires electricity. This dependence can be a reason to combine forces and foster substitution of the condensing boiler.

This research has shown that interactions can be found between the implementation processes of two competitive technologies. Some differences in the functioning of the system functions created a competitive advantage for one technology, hampering the process of the other. So far, competing technologies were seen as part of the environment instead of including them in the TIS analysis. It is important to over think this approach and to think of a measure to include competitive technologies in the TIS analysis.

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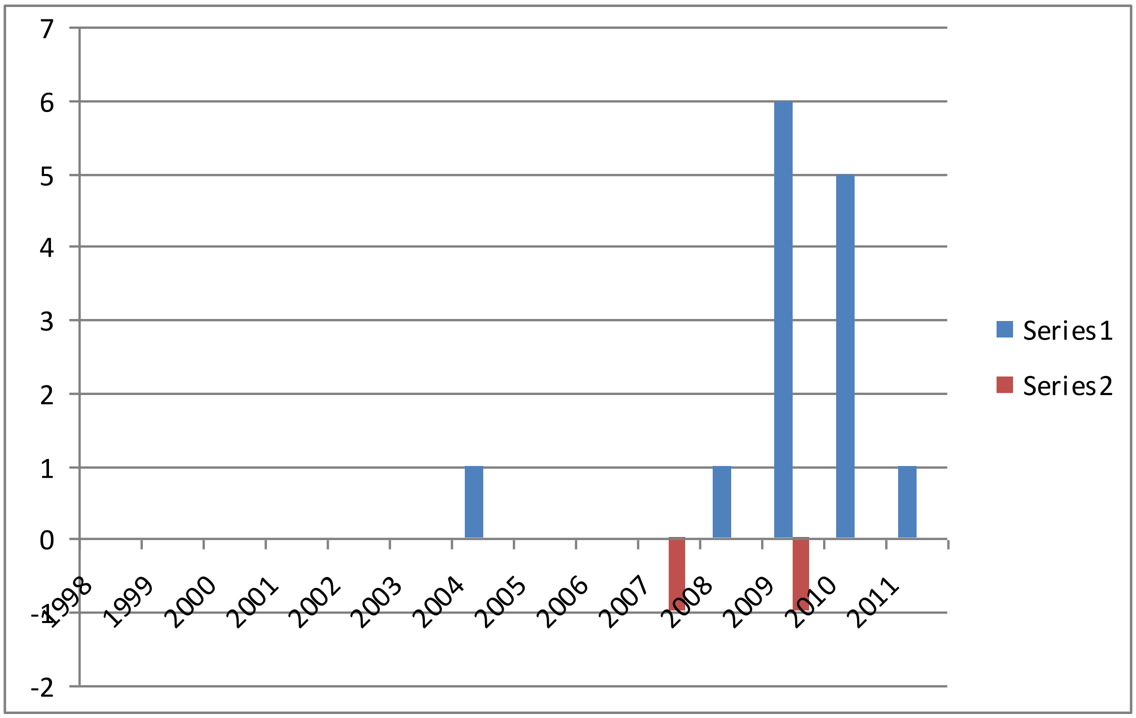
Appendix A: Event analysis

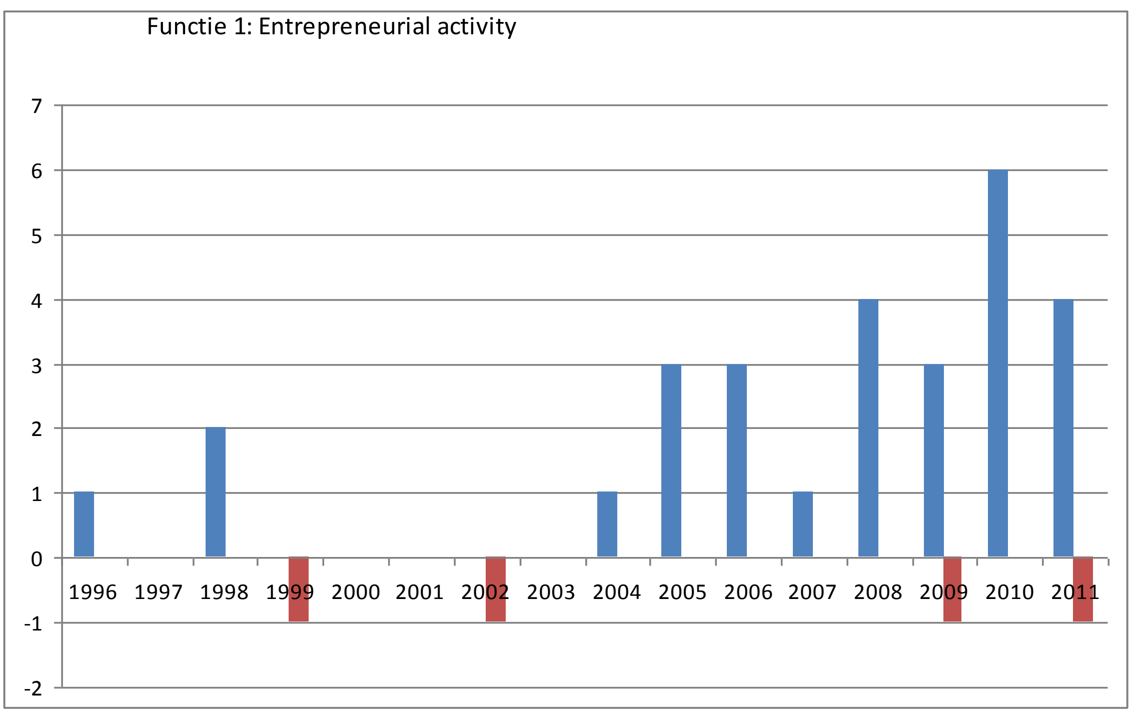
The graphs below show the number of events per system function over time. The blue bars above the zero line indicate positive events, fostering the implementation process. The red bars below the line indicate negative event hampering the implementation process.

Entrepreneurial activity (F1):

Micro CHP:

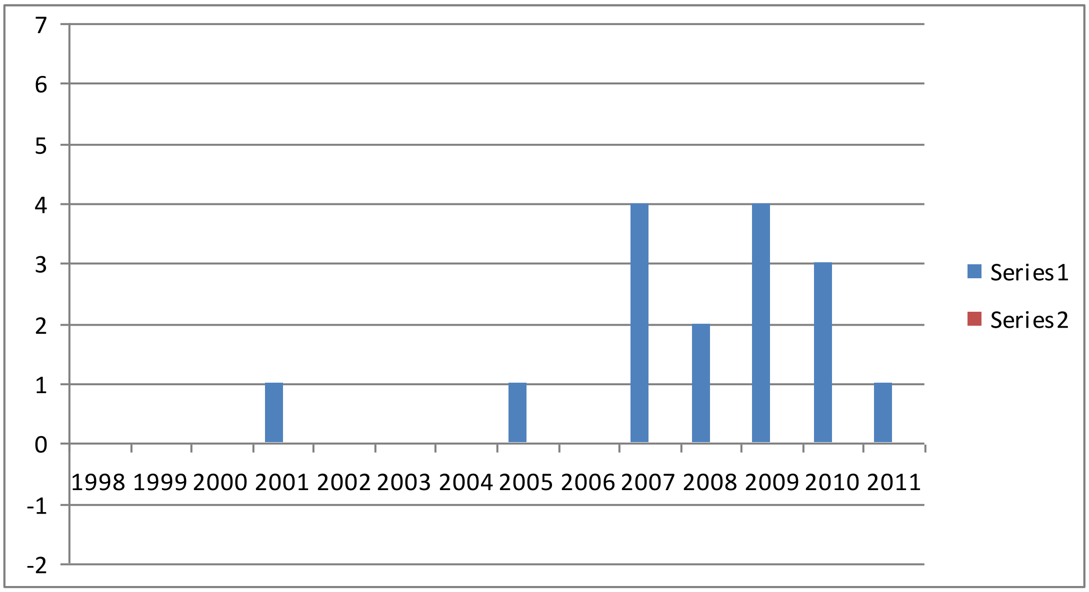


HHP:

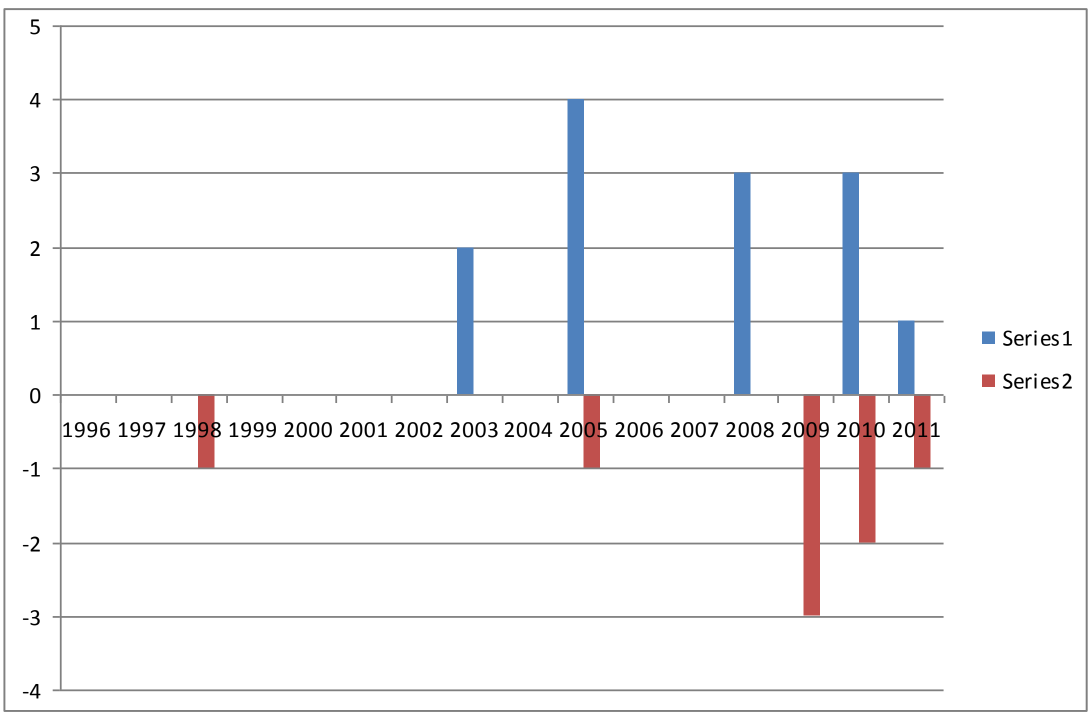


Guidance of the search (F4)

Micro CHP

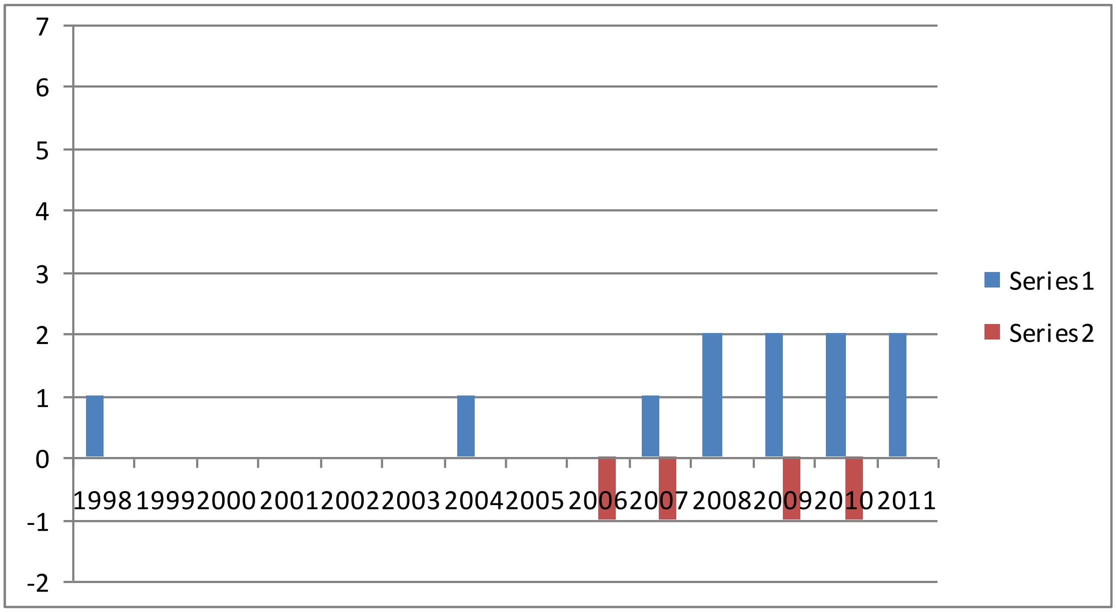


HHP:

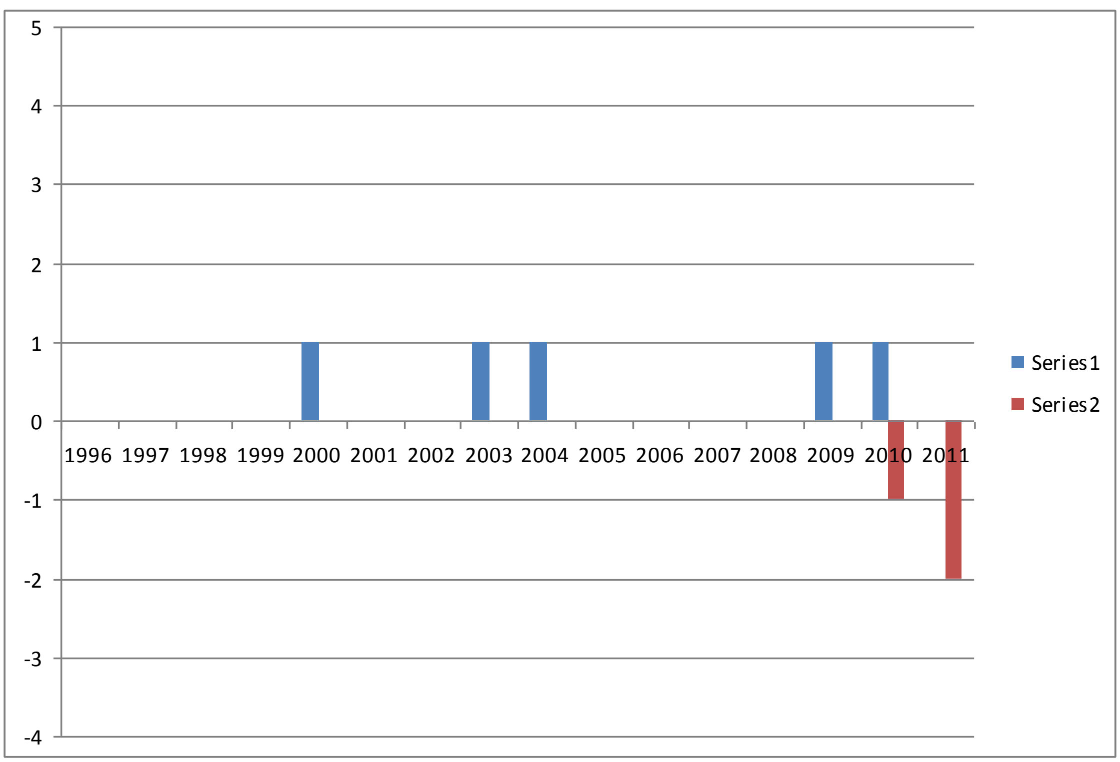


<u>Creation of legitimacy (F7)</u>

Micro CHP:



HHP:



<u>Appendix B: Questionnaire</u>

<u>Interview questions</u>

Personal questions:

1. What is your name?
2. Function within the company
3. How long have you been working for this company

Company questions:

1. How long have you been active in the HHP sector?
2. How many employees does your company have?
3. Are you working in other market areas?
4. What is your business about within the HHP sector?
    a. Producer
    b. Salesman
        i. Who are your suppliers
    c. Other
5. Do you consider your company a stable factor within the HHP market?

Questions regarding system functions

<u>Entrepreneurial activity</u>

1. How many producers are active in the HHP sector at this moment
    a. How many suppliers?
    b. Can you give the names of those firms?

2. Can you give a timeline of when, and which firm, entered the market?

3. How many producers are active in the micro CHP sector at this moment
    a. How many suppliers?
    b. Can you give the names of those firms?

4. Can you give a timeline of when, and which firm, entered the market?

5. How many entrepreneurial experiment has your company carried out in the HHP sector? (for example: tests in laboratories, implementing the technology)

a. Can you give me examples and elaborate them?

6. Is there a lot of competition within this field?
    i. Particularly from other HHP producers?
    ii. Particularly from other competitive technologies?
   b. Does the technical variance in HHP's affect your implementation process in a negative way?
    i. Would it not be clearer for customers if there was little variance?
    ii. Shouldn't producers focus more on implementing the HHP instead of bringing several products to the market that are not applicable in the existing housing market?

7. Do you look at your competitors (also micro CHP sector) and follow their entrepreneurial experiments?

   a. Do you think your entrepreneurial activity is influenced in any way by those firms? (Do you for example increase your entrepreneurial activity to create competitive advantage)

Knowledge development

1. Does your company have R&D projects (investigative activities to improve the technology) in the HHP sector?
   IF YES:
   a. Can you give a number (per year, per month)
   b. Can you give a degree of variety of the projects

2. Does your company have patents for the HHP technology?

   IF YES:
   a. How many?
   b. On what?

3. How much money does your company spent on R&D?
   a. How much is that compared to total money spent?

   IF None of the above:
   - Why not?
   - How does your company get access to knowledge?

4. Does the knowledge, developed in the micro CHP sector; has any influence on your R&D projects or budget?

The role of knowledge diffusion

1. Do you have collaborations of any kind with other firms?

    IF YES:

    a. How many?
    b. Can you give me names?
    c. Are these national or international or both?
    d. What kind of collaborations?
    e. With competitive technologies?

    IF NOT:

    f. Why not?

2. Do you organize, or participate at, official gatherings with regard to HHP?
    a. What kind of gatherings:
        i. Conferences
        ii. Meetings
        iii. Platforms
        iv. Workshops
        v. Other
    b. What were they about?
    c. Do these gatherings involve competitive technologies?

    IF NOT: Why?

3. Is any knowledge diffused from micro CHP technology?
    a. IF YES: How has that influenced your implementation process?

Guidance of the search

1. Are there any specific targets set by the government regarding implementation of HHPs?
    a. What are those targets?
    b. How does your company act upon these targets?

2. From a subsidy point of view, do you think the government sees more potential in micro CHP, instead of HHP?

3. What are your expectations (growth potentials) on this technology? (Potential studies state that in favourable circumstances a growth up to 4 million installed HHPs till 2030 is expected)
    a. Do you think that is realizable?
        i. Under what circumstances?

4. What are your expectations (growth potential) of Micro CHP? (Potential studies state that in favourable circumstances a growth up to almost 4 million installed micro WKKs till 2030 is expected)
    a. Do you think this is realizable?
        i. Under what circumstances?

5. Is the potential of HHP influenced in any way by micro CHP?
    a. How?

6. Do you involve lead users in the implementation process?
    a. How often?
        i. Once a month
        ii. Once a week
        iii. Other
    b. How?
    c. Is there clarity about the demand of lead users?

7. Do you do any other forms of UPI
    a. How?
    b. What kind of users can be identified and how is their demand articulated?

<u>Market Formation</u>

1. In what market stage would you say the HHP is in?
        i. No introduction yet
        ii. Market introduction stage (Costs high, no profit, customers have to be prompted to try the product)
        iii. Growth stage (sales volume increases, public awareness increases, start to make profit)
        iv. Maturity stage (Costs are lowered, increase in competitors)
        v. Other
    b. And the micro CHP technology?
        i. Does that influence your implementation process? (For example, if it is in a later stage, do people tend to go for the micro CHP)

2. How much HHP's have you installed?

3. The subsidies:

    a. (Onno Kleefkens) There are some contradictions in the information on your website, on the one hand I found this on the other this. How can I interpret this?
    b. Is it designed properly concerning the access criteria?
    c. Do you consider it high enough?
    d. Does that give you a (dis)advantage against micro CHP?

4. On which market segments do you focus? Who are your clients?
    i. Private
    ii. Large housing corporations
    iii. Other

5. How many firms are able to install and maintain a HHP (or micro CHP)?

6. Do you advertise your product?

    a. In what way
        i. Newspaper
        ii. Internet
        iii. Other

Resource Mobilization

1. How do you perceive the access to sufficient resources (human capital, financial capital, complementary assets)?
    a. Problematic
    b. Easy

2. Why?

3. IF a) Where do the problems lie?
    a. Human capital (education, entrepreneurship, management)
    b. Financial capital (seed and venture government funds)
    c. Complementary assets (complementary products, services or networks infrastructure

4. Is, in your opinion, the access to sufficient resources influenced in any way by the micro CHP sector (or other competitive technologies)? (Does it for example limit your access due to more parties?)

Creation of legitimacy

1. What is the public opinion towards this technology
    a. How is it depicted in the media?

2. In what way is this vision influenced by other competitive technologies (micro CHP)?
    a. For example: Do pleaders for other technologies bring the HHP technology down?
    b. Or do people see them as a combination?

3. How many interest groups lobby for HHP

    a. Can you name a few?
    b. What are their main arguments pro, and against, HHP?
    c. Do they plead for HHP or for heating systems in general?
    d. IF GENERAL: Would it be better, in your eyes, to have them plead for one technology, or do you think that this only generates more attention?
    e. Can you name a few lobby actions?