# When heat becomes hot business

*An innovation system perspective on barriers to BioGrid and District Heating development in the Netherlands*

**Master thesis for Science and Innovation Management (45 ECTS)**

*4 June 2013*

Utrecht University
Master student Science and Innovation Management
Guillaume Goijen, BASc (g.l.h.goijen@students.uu.nl)
Student number: 3727041
Gildstraat 64, 3572 ER Utrecht
University supervisor
Dr. Gaston Heimeriks (g.j.heimeriks@uu.nl)
Second reader
Mrs. Dr. Simona Negro (s.o.negro@uu.nl)

Alliander N.V.
Company supervisor
Dr. ir. Harry van Breen MBE (harry.van.breen@alliander.com)

alliander

Universiteit Utrecht
Faculty of Geosciences

# Prelude

*"Science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are part of nature and therefore part of the mystery that we are trying to solve"* (Max Planck, 1932, in 'Where is Science Going?'). This reminds me, when striving for sustainability or another noble cause, that one self is part of the solution, the answer, the journey, the quest, the process, and the analysis of such. In this light I am proud to present you my master thesis: the final piece after marvellous student years.

I have worked with great pleasure on the 'hot topics' that BioGrid and District Heating both are. It was nice to be able to participate and work at the strategy department of Alliander. Therefore, I want to thank Harry van Breen in particular. He helped and guided me as my company supervisor professionally through the process. He gave me the space to develop my own thoughts and methods, but nevertheless was available for direct commentary when needed. Needless to say, that I gratefully thank Clare Groosman, because she helped me to acquire this marvellous project. I want to thank Daniëlle Putman Cramer, because she encouraged me to put myself to the test in this master and fully supported me throughout this thesis. I can be grateful that she created the space that I needed to work on this project, especially in the final weeks.

Also I want to thank Gaston Heimeriks, who on behalf of the master Science and Innovation Management at Utrecht University supervised me during the project. Particularly during the proposal phase discussions about which theoretical point of view to adapt helped sharpening the research scope. Furthermore, I want to thank the second reader of my thesis, Simona Negro. I want to thank all interviewees for their cooperation on the project and last but not least, my colleagues at Alliander. They made the whole process more enjoyable with numerous coffee breaks, intellectual chats, and sometimes nonsense.

I hope you will enjoy reading this thesis and be able to move forward from the presented results.

Guillaume Goijen, BASc
Utrecht, 4 June 2013

# Abstract

The current energy system is not sustainable and changes are needed. However, these changes are hampered because of various reasons. This research investigates the barriers specific to the development of the Dutch BioGrid and District Heating innovation systems. The adopted research methods comprise of a literature review, expert interviews, social network analysis, and event history analysis; with according empirical data. For the Event History Analysis the addition of a cumulative graph of the results provides deeper understanding of the Technological Innovation Systems (TIS) functions over time. The assessment of the phase of development, the structure, and functioning of the innovation system in combination with the systemic problems framework provides a solid ground for the identification of barriers to innovation system development. The in the overarching analysis identified barriers are discussed and linked to their respective sources. This thesis moves further by providing recommendations for fostering the development of both technological innovation systems.



*Keywords: Technological Innovation System, TIS, functions of technological innovation system, Systemic problems, District Heating, BioGrid, Event History Analysis, Social Network Analysis, Barriers to TIS development*

# Content

# 1. Introduction

In the past years it has become generally acknowledged that the current fossil fuel dependent energy system is not sustainable and alteration of the present state of affairs is needed (ECF, 2010; IEA, 2011). The Dutch energy system, following the European climate goals, is presently in transition towards a more sustainable system by means of energy efficiency and the use of renewable energy technologies. This transition sets the scene for disruptive changes; with consequences for current market parties and opportunities for new entrants (Christensen et al., 2002). The energy transition is challenging (Patil et al., 2006), mostly because institutional alignment is always in favour of the 'old' technology (Chandy & Tellis, 2000; Unruh, 2000). This issue is often referred to as the path dependent and irreversible nature of technological development (Arthur, 1989; David, 1985). Because of these characteristics innovation is crucial to deal with the negative side effects of the current fossil dependent energy system, such as greenhouse gas emissions (Hekkert & Negro, 2009). However, potential disruptive changes within the Dutch energy system are yet to occur (IEA, 2008). This especially becomes clear when looking at the Dutch heating sector, where historically over 86% of the domestic space heating need is delivered by natural gas burned in gas condensing boilers (Alliander, 2012; CBS, 2013).

In setting goals for sustainable development the Netherlands operates in line with EU targets (Ministerie EL&I, 2011). According to these targets the $CO_2$ emissions are to be reduced with 80% by 2050 compared to 1990 emissions (IEA, 2011); for 2020 this norm is already 20%. Carbon dioxide emission reduction has to be achieved by higher energy efficiency, as well as, the use of sustainable energy sources (A. Bergek et al., 2008a; IEA, 2011; Pront-van Bommel, 2012). According to the International Energy Agency (IEA, 2011): *"We can and must change our current energy and climate path; energy-efficient and low/zero-carbon energy technologies for heating and cooling in buildings will play a crucial role in the energy revolution needed to make this change happen."* (IEA, 2011). More specifically, the Dutch government aims at improving the energy efficiency and greening the energy sources of new buildings. In due course this is implemented for existing buildings, both housing as utility buildings; of which an overarching policy instrument is formed, the energy performance for areas (NEN, 2012). For new housing this is operationalized with the Energy Performance Coefficient[1] (EPC). The EPC norm represents the energetic performance of a building (Bouwbesluit, 2011; Rijksoverheid, 2012). This policy instrument follows the rational that improved energy efficiency leads to less energy consumption, which in the end will result in lower greenhouse gas emissions. In Table 1 the development of the EPC over the past and upcoming years is presented. The EPC it set in Dutch law until the 2015 value of 0.4, the 2020 norm of 0.0 is still a governmental ambition, but likely to be applied.

---

[1] Translated from Dutch: Energieprestatiecoëfficiënt. The EPC of a house only encompasses the building-related energy consumption. Thus, energy required for the heating or cooling of the indoor climate, domestic hot water, and lighting. The EPC requirement only specifies the minimum energetic performance which housing must meet. In the long run the goal of the EPC is reduction of the Dutch carbon footprint (Rijksoverheid, 2012).

In fact, the Dutch dominant heating design is not able to cope with the forthcoming EPC norms. In addition, the Dutch energy transition causes increased interest in environmental friendly residential heating technologies (Alliander, 2012; Ministerie EL&I, 2011). From entrepreneurial perspective, there are great opportunities in the potentially disruptive changes in the heating sector (Alliander, 2012; Christensen et al., 2002). The changes form opportunities for entrepreneurs and create possibilities for new business development. From a systems perspective, the process of diffusion of the heating technologies is reflected in the formation and growth of innovation systems (Bergek et al., 2008a; Hekkert et al., 2011). In the next paragraph a closer look at heating technologies in the Netherands is presented.

Table 1: Development of the Dutch EPC norm (Bouwbesluit, 2011) *the presented 2018 and 2020 norms are an ambition of the Dutch government; the previous are embedded in Dutch law.

| Implementation date | EPC |
|---|---|
| 1-1-1996 | 1,4 |
| 1-1-1998 | 1,2 |
| 1-1-2000 | 1,0 |
| 1-1-2006 | 0,8 |
| 1-1-2011 | 0,6 |
| 1-1-2015 | 0,4 |
| 1-1-2018 | 0,2* |
| 1-1-2020 | 0* |

## 1.1 Heating technologies in the Netherlands

Space heating is as old as human civilization. In past times Dutch households used wood in fireplaces for residential heating (Junginger et al., 2010; Stockroos, 2001). Hereafter a long tradition of peat burning stoves emerged (Stockroos, 2001). Henceforth, due peat depletion and better coal delving technologies, coal arose as the leading energy source for warmth (Lintsen, 2005; Stockroos, 2001). After finding the Dutch gas fields, natural gas became the main energy source for residential heating in the Netherlands (Lintsen, 2005; Rijksoverheid, 2012). Gas condensing boilers were introduced on the European market in the early 1980s as a further development of boilers, which were introduced in the heating sector in the late 1950s (Junginger et al., 2010). With the stricter EPC norms gas fired heating becomes less and less attractive to use as an energy source for space heating (Agentschap NL, 2010), and thus change towards 'new' more sustainable space heating system(s) is at hand (Alliander, 2012). In a broad study assessing end users (over 1500 respondents) as well as technological possibilities, Alliander (2012, pp.33) identified a number of heating systems to be potentially viable for the Netherlands. Furthermore, the research indicated that there are no particular user preferences at the individual level.

European $CO_2$ emission reduction targets, the stricter Dutch EPC norms, the upcoming depletion of the Dutch gas reserves (Ministerie EL&I[2], 2011); and consequent potential reliance upon foreign gas reserves, set the scene for the transition towards other heating technologies (Alliander, 2012). Two systems in particular are identified to be promising for the Netherlands: The BioGrid system and District Heating system. These technological systems are both potentially disruptive given the current market domination of gas fired condensing boilers for heating and the present institutional

[2] currently renamed to the 'Ministerie van Economische Zaken' (Ministry of Economic Affairs)

alignment that favours the existing system (Christensen et al., 2002; Christensen et al., 2006). Both infrastructural technologies will form the focal points in the presented research. Consequently, this thesis sets out to investigate the associated socio-economic barriers to innovation related to these technologies and their particular innovation system; both are briefly introduced below in paragraph 1.2 & 1.3.

### 1.1.1 BioGrid (BG)

A BioGrid is a technical system, in which gas of variable methane quality can be distributed among users connected to this grid (Hardi, 2011). This enables the direct usage of biogas. Where Gasunie has held the monopoly on natural gas for decades, now new gas suppliers can make their entrance onto such regional grids. The BioGrid system allows for the direct use of biogas without 'upgrading' the biogas to green gas. Green gas is biogas that has been improved to the Dutch natural gas standard (NEN, 2011). This enables direct use of biogas and saves the need for an investment intensive 'upgrading station'[3]. In a BioGrid system a biogas production facility (most often a biomass digester) will supply biogas suitable for pipeline transportation. After filtering moisture and other content the biogas is free of harmful contaminations and is suitable for safe operation in adapted residential central-heating boilers (Hardi, 2011). A dedicated distribution station will supply the biogas to the distribution grid. The grid connects the distribution station to all residential buildings in the BioGrid area. All residential heating boilers connected to this grid will be equipped with a modified burner capable of dealing with variable gas quality. This multi-gas boiler is developed in a collaboration of Alliander and ATAG. The BioGrid will include both gas quality and volumetric measurements (Hardi, 2011).

Modifications to accommodate biogas in the gas chain are not carried out within the gas production and distribution itself, but on the equipment of the end-user (the multi-gas boiler). Residential central-heating gas condensing boilers in the Netherlands operate on Groningen natural gas. These traditional boilers cannot operate on variable-quality methane at lower heating values (Hardi, 2011). Currently, a multi-gas boiler has been developed, capable of dealing with low and variable caloric values of the used gas. At present, Alliander is deploying three BioGrid pilot projects; further development of the portfolio is looked into. The BioGrid is specifically designed for the Dutch heating market, however somewhat similar systems, in which biogas is used directly for example for cooking, arise in rural areas of developing and BRIC countries.

### 1.1.2 District heating (DH)

District heating is a technical system for the distribution of heat generated in a central location. Heat for residential and commercial heating requirements. Two types of district heating systems can be identified: 1) *Residual district heating system*, this system uses a residual (waste) heat stream from for example an electricity plant to feed the district heating system. 2) *Autonomous district heating system*, this system is not reliant on residual heat streams but has its own autonomous heat source. An autonomous district heat source can be for example geothermal or seasonal storage with backup heating. In Europe there are more than 5.000 District Heating systems, currently supplying more than 10% of total European heat demands with an annual turnover of €25-30 billion and 2 EJ (556 tWh) heat sales. Looking at Europe, diffusion of District Heating is unevenly distributed, being close

[3] Translated from Dutch: Opwaardeerstation; this is technology for the upgrading of biogas to green gas.

to zero in some countries while reaching as high as 70% of the heat market in others. In the Netherlands in 2011 approximately 550.000 households are connected to district hearing. The market share of district heating in terms of households was 7,4% (CBS, 2013). The district heating systems began were firstly developed in the seventies and eighties of the previous century, nevertheless the technology never fully developed. Up until more recently, amongst others, the municipality of Amsterdam in 2009 a large district heating project started, currently connecting over 45.000 households with a yearly expansion capacity of 4000 homes (Gemeente Amsterdam, 2009). Amsterdam is currently looking into further greening of the City (Nieuwsbank, 2013). These developments have not been unnoticed and other regions are becoming interested in the possibilities of district heating. Still the DH concept does not live up to full expectations as expressed in the starting days of this technology (IEA, 2011). At present Alliander is assessing and working on a residual district heat project for the municipality of Nijmegen.

## 1.2 Systemic problems and barriers

With the development of an innovation system numerous challenges arise (van Alphen, 2011; Bergek et al., 2008; Wieczorek & Hekkert, 2012). This also counts for innovation systems of sustainable heating technologies, as BioGrid and District Heating[4] are. Given current conditions for the Dutch heat sector the development and deployment of both technologies could be hindered due to barriers in the innovation system. However, according to the IEA (2011) is district heating a promising alternative to the use of gas condensing boilers and the BioGrid has been coined as a potential disruptive system (Alliander, 2012; Hardi, 2011), as a new rational is needed compared to the 'old' status quo gas grid. However, in his seminal paper (Unruh, 2000, pp.817) states that: *"industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale. It is asserted that this condition, termed carbon lock-in, creates persistent market and policy failures that can inhibit the diffusion of carbon-saving technologies despite their apparent environmental and economic advantages."* Nevertheless, concrete action suggestions to move away from such carbon lock-in, even in later papers, are not proposed (see for example: Unruh, 2002). Other scholars suggest that a lock-in is not a barrier by itself but an outcome of multiple other existing barriers (Foxon et al., 2007; Wieczorek & Hekkert, 2012). Investigating barriers to technological development it thus relevant to understanding lock-ins and fostering sustainable development.

Assessing technology specific barriers can help escaping this carbon lock-in. In search for these barriers the '*systemic problem'* framework (Negro et al., 2012; Wieczorek & Hekkert, 2012) provides handhelds for the identification of barriers to the development of a technology from an innovation system perspective. The literature refers to systemic problems as 'system failures', 'weakness', 'imperfection', 'hampering factors', or 'problems'. This thesis adopts Wieczorek & Hekkert's (2012) definition of systemic problems as: *problems that arise at the innovation system level and which negatively influence the speed and direction of innovation processes*. Examples of systemic problems are: Market structure problems, Infrastructure problems (physical and knowledge), Institutional problems (hard and soft), Interaction problems (too strong and too weak), Capability problems, etc. Underlying systemic problems are technology specific barriers that can be found by assessing the

[4] Depending on the system's heat source

structure and functioning of the Technological Innovation System (TIS) of the technology of interest (Wieczorek & Hekkert, 2012). Wieczorek & Hekkert (2012, pp.81) provided a typology of systemic problems; this typology is adapted to match this research by the addition of technological problems. This term is added in order to capture the technological complexity of the heating technologies under study. The utilised typology thus consists of: *Actor problems*, i.e. poorly articulated demand, or capability failures; *Institutional problems*, i.e. unclear subsidies schemes or regulations favouring the current system; *Network problems*, i.e. lock-in failures or poor connectivity; *Infrastructural problems* (physical, knowledge, finance), i.e. mismatch between basic and applied research, investment issues; and *Technological problems*, compatibility with existing technology or better alternatives.

## 1.3 Research question

This study aims to investigate barriers to BioGrid and District heating development by applying the Technological Innovation System Functions approach combined with the systemic problem framework. From such TIS analysis – with the systemic problem framework as a conceptual construct – barriers can be identified when comparing the data with the supposed functioning of the innovation system for that phase of development (see for example Figure 3). For each phase a different set of functions is leading (Hekkert et al., 2011), therefore it is important to understand the phase of development of the technologies under study. Consequently, and taking the before mentioned into account, an exploratory research questions has been formulated to meet the overall objectives of this thesis:

> *What are the barriers to BioGrid and District heating development in the Dutch heat innovation system?*

The reasoning for this geographical demarcation on the Netherlands is that the Dutch heat industry high a particular high usage of individual gas condensing boilers. In addition, the BioGrid concept is developed in the Netherlands and the first pilots are located in the grid area of the Dutch public utility firm Alliander N.V. In order to answer the overall research question the following three sub-questions (SQ) are formed. Firstly, the phase of development of both technologies is looked into and assessed what this means for TIS structure and functioning, as for each phase of development a different set of system functions is needed to drive further development of the technology. Therefore, first sub-question one is answered:

> *What is the phase of development of BG and DH and what are the important system functions for that phase?*

Secondly, the TIS structure of both technologies is mapped, assessing the technology, actors, network, and institutions. The structure is necessary to understand where potential systemic problems arise in the system. This answers sub-question 2:

> *What does the Dutch technological innovation system for BG and DH look like?*

Lastly, the functioning of the residential heating technologies is investigated. This answers the third sub-question:

> *How are the Dutch BG and DH innovation systems functioning?*

The functional assessment of the two TIS's is set up against the proposed beneficial set of functions for the phase of development of the technologies. From that last step in the analysis the technology specific barriers for further development of the BioGrid and District heating TIS can be deduced.

Accordingly, from the answers of these three sub-questions barriers to development of the heating technologies can be identified.

This study adds to research on barriers to renewable energy technology development. It can benefit policy makers in understanding where to intervene and adjust current instruments for the benefit of the most desirable technology (Christensen & Rosenbloom, 1995). There is already knowledge about which technologies are viable for the Dutch heat economy from consumer point of view (see for example Alliander, 2012). However, why innovation occurs so slowly in the heating sector is not fully understand. This research contributes to that understanding by aiming at the identification of BioGrid and District heating specific barriers from out innovation system perspective.

The innovation system perspective in combination with the systemic problem framework is a heuristic that allows for analysis of technological systems from a broad perspective and acknowledges that innovation does not occur in isolation. Technological innovation occurs in a complex system that consists of many different actors and institutions (Alkemade & Suurs, 2012; Negro et al., 2012). The Diffusion of Innovations theorem of Rogers (2003) seems appropriate to study the research question, however this perspective is not capable of the description of large technological complexes and the accompanied barriers to innovation in such technology specific system. The Large Technical systems perspective as posed by Hughes (Hughes, 1987) appears more suitable, nevertheless is that theory not fully capable of catching new emerging technologies and technological systems in the making. Therefore the innovation system approach is an appropriate choice to study the barriers to technological development. Some notions from the Social Construct of Technology (SCOT; Pinch & Bijker, 1984) framework might be appropriate, but does not enrich the presented TIS framework as the barriers and perceptions of society towards a technology is taken already into account in the innovation systems perspective. Combining the innovation system theory with a social network analysis in combination with sequence analysis allows for exposing numerous activities, system actors, and mutual relations in a structured method and can therefore give a very broad and comprehensive picture of the innovation system.

The barriers to technological development of BioGrid and District heating shall be studied from an innovation systems perspective adopting the following research methods: *social network analysis* (van Alphen, 2011) which investigates the actors and their network and *event history analysis* (Negro, 2007; Suurs, 2009) answering the functioning of the innovation system, substantiated and validated by *expert interviews* (Alphen, 2011; Negro, 2007; Suurs, 2009). The expert interviews are used to gain insight in the institutions of the innovation system, retrieve new actors to the field, and discussing the preliminary answers. The adapted methods and data used are further elaborated on in Chapter 3. By identifying the barriers to innovation and introducing an innovation systems oriented perspective, this research contributes to the existing body of mainly technological oriented literature on the residential heating technologies. In addition, it can help policymakers and entrepreneurs to widen their focus beyond regulatory measures, by finding underlying barriers that impose direction and hamper the development of the BioGrid and District heating innovation system. At the end of this thesis recommendations for further development are presented that might enhance innovation system performance for both technologies.

The remainder of the chapters in the thesis consist of the following: in Chapter 2 the Theoretical framework on which this research builds is discussed; In Chapter 3 the Research methods adopted data used are elaborated on. Hereafter Chapter 4 and Chapter 5 handle the results of respectively the BioGrid and District heating innovation system. In Chapter 6 the Analysis is set forth and Chapter 7 withholds the Discussion of the presented research. In Chapter 8 Conclusions to the research question and sub-questions are presented. Chapter 9 elaborates on Recommendations for further development of both technologies. The quoted and referred literature is found in Chapter 10 and finally the appendices are placed in Chapter 11.

# 2. Theoretical framework

The theory that frames this research on barriers to the development of the innovation systems of BioGrid and District heating is elaborated in this chapter.

## 2.1 Technological development and innovation literature

When looking at the present state of the Dutch heating sector it becomes clear that most of it comprises of large incumbents, incapable or unwilling to change their business as usual (Chandy & Tellis, 2000; Unruh, 2000). For them there is no incentive to cannibalize their market share by introducing new technologies. Cannibalizing market share prevails in conjunction with the notion of creative destruction (Christensen & Bower, 1996), a term first coined by Joseph Schumpeter in his seminal innovation paper. He claims that in essence innovation is not possible without the destruction of knowledge; the 'new' overtakes the 'old' (Christensen et al., 2002).

The sheer size of the residential heating market makes abrupt change difficult (Arthur, 1989; David, 1985). The heating technologies presented in this research are both potentially disruptive in the Netherlands (Christensen et al., 2006). In addition, societal preferences may impose technologically undesired directions in the innovation process (Pinch & Bijker, 1984). Understanding barriers to innovation and innovation system development can benefit policymakers and strategists that are aiming to change the heating market and entrepreneurs that strive to reap from those at hand changes. The earlier discussed EPC is a policy instrument imposed by the Dutch national government that fosters higher energy efficiency and thereby use of other heating technologies for new buildings (Christensen et al., 2002; Christensen & Rosenbloom, 1995).

A significant strand in innovation literature that seeks to understand innovation and its barriers is the innovation systems approach (i.a. Bergek et al., 2008b; Foxon et al., 2007; Hekkert et al., 2007; Hekkert & Negro, 2009; Markard & Truffer, 2008). According to these scholars innovation should be regarded as part of an eco-system, a broader system, and not a linear process as the 'technology push' and 'market pull' models suggest. Such innovation system is defined as the network of actors and institutions that directly affect the rate and direction of innovation in a society (Bergek et al., 2008; Bergek, Jacobsson, & Sandén, 2008; Bergek, Jacobsson, Carlsson et al., 2008; Carlsson & Stankiewicz, 1991; Hillman et al., 2008; Negro et al., 2008; Suurs & Hekkert, 2009; Suurs & Hekkert, 2009; Suurs & Hekkert, 2009; van Alphen et al., 2010). There coexist various innovation system approaches, each with different focus. Focusing on regional, national, sectorial, or technological aspects (Hekkert et al., 2007). Within the context of technological innovation, the latter, the TIS approach, is most relevant with respect to the purpose of this study. Various, sometimes competing, technological innovation systems can be present at the same time. According to Carlsson and Stanckiewicz (1991, pp.111), a technological innovation system is defined as: *"[...] a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology."*

In this research a TIS approach is applied to analyse the complex techno-institutional structure of the heating system; more precisely, the residential heating innovation systems of BioGrid and District heating. In TIS literature such analysis is set forth by pointing out the key actors, institutions, and other technologies that affect the development of the technology under study. Such analyses especially stress that it is the relation between different structures that shape technology (Alphen, 2011). For a technology to develop successfully and eventually diffuse into society, it is required that a TIS with relatively coherent structures is present (Suurs & Hekkert, 2009). On the other hand an innovation system should function properly in order that a technology can become successful. This approach is covered by the technological innovation system functions approach (Hekkert et al., 2007). The remainder of this chapter the theoretical framework concerning the structure of the TIS (2.2) the phase of development (2.3), and TIS functions (2.4) are elaborated on.

## 2.2 Structure of the TIS

The structure of the innovation system (See Figure 1) consists of three major innovation system components. Carlsson and Stanckiewicz (1991) describe the components of an innovation system to be: *Actors*, *Networks* and *Institutions*. *Actors* – also known as stakeholders (Freeman, 1984) – are firms or participants and all play a role in the innovation system; whether they are consumers of the energy, suppliers or venture capitalists, as well as many other organizations. Hughes (1987) highlights a particularly important actor, who is the ‘prime mover’ or ‘system builder’, an actor (or set of actors) who are so financially and/or politically powerful that they can strongly influence the development and diffusion process. *Networks* constitute channels important for the transfer of both tacit and explicit knowledge and other resources between different TIS actors (Jacobsson & Johnson, 2000). Some networks are built around markets. These contribute towards the identification of problems and the development of new technical solutions that are presented by potential buyers and sellers. Networks do not necessarily have to be market related. They can also allow for the sharing and transfer of knowledge. In addition, influence can be directed in certain pathways that can guide the decisions of firms and other organizations. Networks are particularly important in the formation, enlargement, and further development of a TIS (Musiolik et al., 2012).

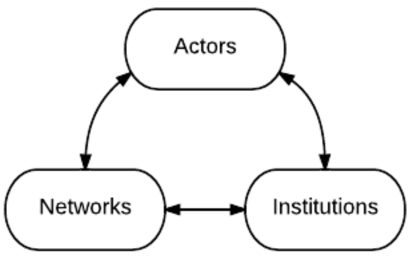


Figure 1: The structure of the technological innovation system. The components mutually interact within the context of the technology.

Technological structures consist of artefacts and the technological infrastructures in which they are integrated. Actors involve organizations contributing to a technology, as a developer or adopter, or indirectly as a regulator, financer, etc. The actors in a TIS can through choices and actions, actually generate, diffuse and utilize technologies (Carlsson & Stankiewicz, 1991). *Institutions* lay down the groundwork, forming the norms and rules that regulate interactions between actors within the network (Edquist, 2005). The paths that institutions take have an impact on the potential of technology that can be fully grasped in terms of the growth of new sectors or industrial clusters

(Carlsson & Stankiewicz, 1991). For actors in an innovation system it can be important to quickly adapt to ‘new’ technology. Because, *"organizations that are able to adopt technological change quickly maximize their probability to being able to move with a changing technological frontier."* (Tushman & Anderson, 1986).

Social network analysis is a method that can provide valuable insight in the TIS structure. It covers the analysis of actors, networks, and to some extent institutions (Alphen, 2011; Wasserman & Faust, 1994). Knowing and understanding the TIS structure is a prerequisite for being able to properly assessing the goodness of the TIS under study (Alphen, 2011; Bergek et al., 2008a). Nevertheless, the goodness of a particular TIS structure in absolute sense cannot be related to any other than to an outcome in terms of technology diffusion (Bergek et al., 2008a). In addition, the structural analysis by itself has proven to be insufficient for covering a complete TIS analysis (Wieczorek & Hekkert, 2012). Therefore, apart from the structural analysis, a functional approach is adopted for the analysis of TIS functioning. Both are supplemented by the systemic problem framework; as described earlier in section 1.2. The so called Seven functions approach aims to investigate how well a technological innovation system is functioning (Bergek et al., 2008a; Hekkert et al., 2007) and is adopted by various scholars to assess the development of (sustainable) energy technologies (i.a. Alphen, 2011; Hekkert et al., 2007; Kamp et al., 2009; Negro, 2007; Suurs et al., 2009). This functional approach is further elaborated on in section 2.4. In the next section the importance of understanding the phase of development of a technological innovation system in delved into.

## 2.3 Phase of development

Several TIS articles specifically focuses on (sustainable) technological development in the energy system (i.a. Alkemade & Suurs, 2012; Hillman et al., 2008; Suurs & Hekkert, 2009; Suurs, 2009; Suurs & Hekkert, 2009; van Alphen, Noothout et al., 2010). These studies are dedicated to capturing the system dynamics that create the context within which technology development can, or cannot, take place (Suurs, 2009; Suurs et al., 2010). Throughout technological development, a TIS moves through a formative stage in which actors are drawn in, networks are formed, and institutions and (existing) technologies are adjusted; to increasingly aligning them to the emerging technology. This innovation system development is represented by the enlarging innovation system ‘boxes’ in Figure 2. In order to be able to move to the next phase, for each phase of development a specific set of functions and function interactions are important (Hekkert et al., 2011; Suurs & Hekkert, 2009). Consequently, when performing an innovation system analysis it is important to know in which phase the technology under study is (Hekkert et al., 2007; Hekkert et al., 2011). In Figure 2 the vertical dotted lines indicates ‘borders’ between each phase. The questions below the x-axis determine the phase the technology is in (van Alphen, 2011). Roughly, if the answer to the question in above Figure is yes, than the technology is in the next phase.

For each phase of technological development different system interaction and functioning is necessary in order to move into the next (Bergek et al., 2008a; Hekkert et al., 2011). For BioGrid and District Heating the phase of development is determined by literature review and expert interviews. This is done in order to find the set of functions that important for that specific technology (answer to SQ1). These interactions provide guidelines to the identification of systemic problems. A schematic representation of the functions and interactions per phase is provided in Figure 3. The black lines important relations, as opposed to the grey ones that are needed but of less interest. In addition, the bold circles are to be the most important function(s) for the specific phase of development. For example for the Pre-development phase, Knowledge Development (F2) is the most important factor (Hekkert et al., 2011). When the phase of development of the studied TIS is identified, it also becomes clear what functions and interactions are needed in the next phase. Limited performance for the necessary functions indicates potential barriers to innovation system development. What the Functions comprise and cover is elaborated on in the next paragraph on TIS functioning.

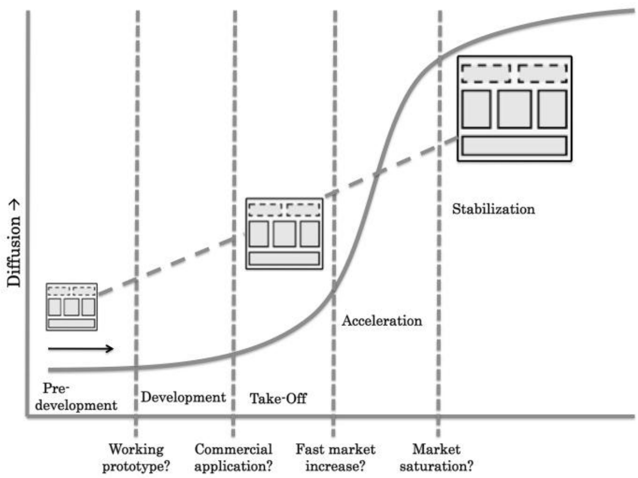


Figure 2: The phase of development on the diffusion curve of a technology. The S-curve indicates the market diffusion of the technology under analysis. The TIS grows in size over each phase of development, indicated by the innovation system 'boxes' (adapted from Hekkert et al., 2011).

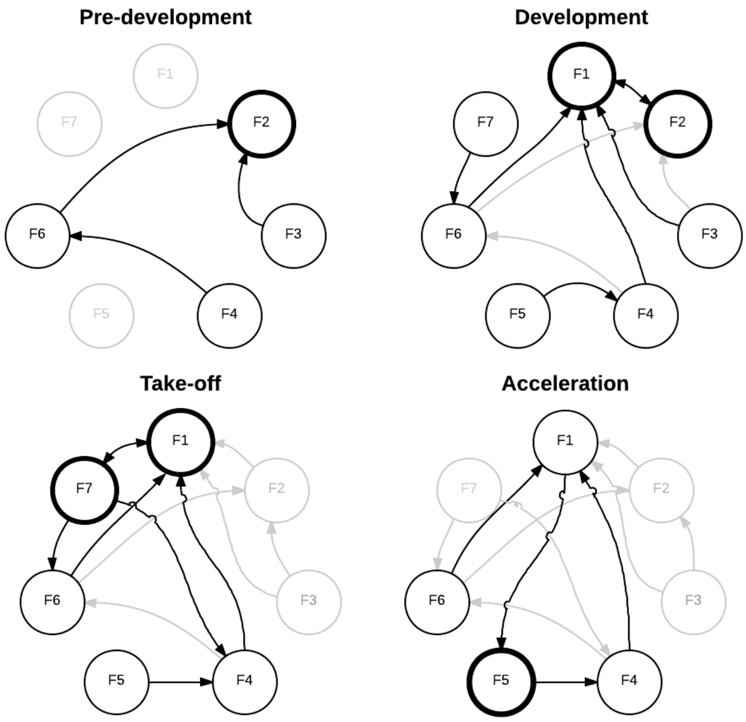


Figure 3: Important TIS functions per phase of technological development (adapted from Hekkert et al., 2011). The numbers correspond with the functions elaborated bellow in section 2.4).

## 2.4 Functioning of the TIS

The dynamics of TIS build-up can be mapped by studying the fulfilment of a set of seven system functions. These system functions are processes that are necessary for successful TIS build-up. Several studies have applied the system functions approach (i.a. Alkemade & Suurs, 2012; Alphen, 2011; Hillman et al., 2008; Negro et al., 2012; Suurs & Hekkert, 2009; Suurs, 2009; Suurs & Hekkert, 2009; van Alphen et al., 2010; van Alphen, Noothout et al., 2010), which has led to a variety of system functions lists in the literature; as discussed by Bergek et al. (2008). This research uses the list of system functions set forth in the seminal paper of Hekkert et al. (2007) and will be applied to map the key activities in the innovation systems of BioGrid and District heating. This is done to describe and explain the system dynamics in order to find potential barriers to further development. This set of system functions is empirically validated by Hekkert & Negro (2009). They assessed a large number of cases in which all functions are found to be useful to describe an innovation system.

The important difference with the *structure* of the innovation system is that these system *functions* are much more evaluative in character. However, one needs to understand which actors, networks and institutions are present before a TIS analysis on the functioning of that particular innovation system can be conducted. Wieczorek & Hekkert (2012, pp.86) showed that the combination of the two analytical frameworks in combination with the systemic problem view is a powerful tool for the analysis of innovation systems. The functions of technological innovation systems (Hekkert et al. 2007) utilized in this research are listed and briefly discussed below. The Function descriptions have been adapted from Hekkert et al. (2007) in order to provide an unbiased Function definition. Each is linked to exemplary activities that can indicate the fulfilment of the functions. Specific events and how they link to the functions are discussed in the Chapter 3.

**Function 1 Entrepreneurial Activities** – the role of the entrepreneur is to translate knowledge into business opportunities, and eventually innovations. The entrepreneur does this by performing market-oriented experiments that establish change, both to the emerging technology and to the institutions that surround it. Activities associated are projects with a commercial aim, demonstrations, and portfolio expansion.

**Function 2 Knowledge Development (Learning)** – this function involves learning activities, mostly on the emerging technology, but also on markets, networks, users, etc. Learning activities relate to both learning-by-searching and learning-by-doing. The former concerns R&D activities, whereas the latter involves learning in a practical context. Examples of activities involved are studies, laboratory trails, and pilots.

**Function 3 Knowledge Diffusion (Through Networks**) – innovations occur most where actors of different backgrounds meet and engage in learning-by-interacting. A special form of such interactive learning is learning-by-using, which involves learning based on the experience of users. Activities concerning this function are conferences, workshops, and alliances.

**Function 4 Guidance (of the Search)** – this function refers to the activities that shape the needs, requirements, and expectations of actors with respect to their (further) support of the emerging technology. Activities associated are expectations, promises, policy targets, standards, and research outcomes.

**Function 5 Market Formation (Creation)** – emerging technologies cannot be expected to compete with incumbent technologies. To support innovation, it is usually necessary to create artificial markets. This involves activities that contribute to the creation of a demand for the emerging technology, such as, niche market formation, tax exemptions, and market regulations.

**Function 6 Resource Mobilization** – this function refers to the allocation of financial, material, and human capital. The access to such capital factors is necessary for all TIS developments. Associated activities are subsidies, and investments.

**Function 7 Creation of Legitimacy/Counteracting Resistance to Change** – the rise of an emerging technology often leads to resistance from actors with interests in the incumbent energy system. In order for an innovation system to develop, other actors must counteract this inertia. Urging authorities to reorganize the institutional configuration of the TIS can do this. Lobby and advice are activities that can achieve this. This function is also coined ‘Counteract Resistance to Change’ and ‘Advocacy Coalition’; often these names are used interchangeably.

# 3. Methods for analysing Innovation System development

In this chapter the adopted research methods are discussed. This thesis aims to develop an overview of barriers to the development of the Dutch BioGrid and District heating innovation systems. Consequently, this study first searches to gain overview over the TIS, next assess its functioning, and thereafter determines what barriers there are related to the development phase of BG and DH. The report of Hekkert et al. (2011) and the paper by Bergek et al. (2008) provide direction for such analysis. They both present a stepwise TIS analysis. However, these analyses are to large extent directed towards policy makers. Another method presented by Wieczorek & Hekkert (2012) better matches the goal of this research and discusses the level and quality of the structural and functional analysis in relation to the systemic problem view. However, they do not provide concrete methodological direction in what specific method and data to use for the suggested structural and functional technological innovation system analysis apart from expert interviews. This research tries to acquire a complete view on both TIS and therefore attempts to further supplement the methodological framework provided by Wieczorek & Hekkert (2012) with other methods that have been successful in TIS analysis.

Methods that have been used previously to map and analyse the structure and performance of an innovation system are both qualitative as quantitative and consist of: literature reviews (van Alphen, 2011), interviews with key stakeholders (expert interviews) (Wieczorek & Hekkert, 2012; van Alphen, 2011), event history analysis (Negro, 2007; Negro et al., 2007; Suurs, 2009); media analysis, project analysis, and patent analysis (van Alphen, 2011); often these analysis were conducted in a combination. This thesis sets out to identify barriers to development from technological innovation system perspective in combination with the systemic problem framework. In order to serve that research aim, firstly a literature review seeks for identifying the current state of affairs of the technologies under analysis and determines the phase of development (answering SQ1). Secondly, the structure of the TIS is analysed. This discusses the technologies, identifying key actors, analysing the network of the TIS, and its institutional surroundings (answering SQ2). Thirdly, the functioning of the examined TIS is discussed and measured using event history analysis (answering SQ3) as suggested by Hekkert et al. (2007) and operationalized by Negro (2007). Events are sought for that impede or drive innovation for the technology under study. *"The data collection in this case is not so much about following all of the individual agents or innovation projects in the system, it contains the events that are reported at system level relevant to a specific technology"* (Negro, 2007, pp.38). The results are commonly presented in the form of a narrative discussing the TIS.

For this research the structure of the TIS is analysed applying social network theory by means of the program 'Gephi' (Bastian et al., 2009), assessing the actors and networks of the technology specific innovation system. The three methods are coupled with expert interviews underlining or rejecting the findings, for the social network analysis this means, the validation of the list of actors and correlating projects. The methods are elaborated on further below. Table 2 provides an overview of the adopted research method per technology. The Event History Analysis for the BioGrid technology is not yet possible due to the relative newness of the innovation system and consequently limited availability of data as only limited empirical data beneficial to an Event History Analysis is built up. Additional interview data of value chain stakeholders – potential biogas producers – will be analysed to sufficient the BioGrid TIS analysis. The adopted methods are discussed in the upcoming three sections; thereafter a section on the used data per research method is presented (see section 3.4).

Table 2: Overview of the technologies under study and the research methods applied for the identification of barriers to the development of the respective TIS.

| TIS\Method | Literature review | Interviews | Event history analysis | Social network analysis |
|---|---|---|---|---|
| BioGrid | X | X | | X |
| District heat | X | X | X | X |

## 3.1 Interviews and Literature review

In order to map the structure of the Innovation Systems and ascertaining to what extent the Innovation System Functions have been fulfilled, semi-structured interviews are conducted with key stakeholders involved in the BG and DH innovation system or overviewing both. To improve the comparability and reliability of the research, a number of indicative questions that provide insight in the fulfilment of the functions have been formulated and adapted from earlier TIS studies (see Appendix 11.1). The preliminary results of the interviews have then been verified and complemented by additional review of scientific, as well as, 'grey' literature (e.g. professional journals, roadmaps, and policy papers). In total, twenty-two interviews are conducted with senior representatives (experts) within the heating sector in the Netherlands, involved with BioGrid and/or District heating. Within the interviewee pool variety is sought (e.g. representatives from all major energy companies). With cross-referencing and external justification, the validity of the group of interviewees is guaranteed. Furthermore, the interviewees are asked to verify and compliment the list of actors and networks (project data) used as data for the social network analysis of the innovation system of both technologies (see paragraph 3.3). To minimize a personal bias of this thesis' researcher and to further assess the system's performance, the interviewees are also asked to reflect upon the on-going activities in the system. The interviewees are too asked on their view on what should be done to improve the fulfilment of system functions that are according to them hampering factors. This method provides the basis for the answer to the overall research question. The acquired data is elaborated on in section 3.4.

## 3.2 Event History Analysis

This research will take a systematic approach by adopting (and adapting) the event history analysis. This method has earlier been applied by Negro (2007), Suurs (2009), and van Alphen (2011) and has proven to be a useful technique to systematically analyse complex longitudinal data. The event history analysis is based on the process approach, a view that conceives of change processes as sequences of events. Based on the process approach, TIS development will be approached as being a meaningful narrative with plots. *"The approach consists of retrieving as many historical events related to a technological development as possible based on professional journals, newspapers and websites. The events are stored in a database, classified and systematically allocated to specific system functions."* (Negro et al., 2007). The event history analysis offers the possibility to operationalize and measure system functions by relating them to events. The interaction between system functions can be measured by tracking sequences of those events. To provide insight in these sequences a cumulative graph is provided. This graph displays the cumulative development of events related to the innovation system function it was assigned to.

The following steps are to be taken for the event history analysis (adapted from Negro, 2007 pp.38-39): 1) A literature search for pieces relevant to the technology, that data source is the academic data source Lexis Nexis[5] (LexisNexis, 2012). For District heating this resulted after selection of useful articles in around 500 articles. For BioGrid only three articles were found, which was according to expectations as this technology is still in the Pre/development phase. 2) Database classification; structure the database according to year, reference, and event category. 3) Allocation of the events to functions, according to event types as presented in Table 3. 4) Summarize the data and construct graphical representation. 5) Write the historical storyline (narrative); to increase the objectivity of this step, the narrative is checked by experts in the field (see also seventh step). 6) Thereafter, identify interaction patterns, barriers, and drivers. 7) Lastly, triangulate the results. The completeness of the data, the event history description, and the results from the analysis are to be verified by field experts. These are contacted via telephone, e-mail, or bilateral interview.

In section 2.4 the functions were discussed and activities were assigned. These activities are event types that can be used to measure the functions. An overview of events per function is presented in Table 3. To the event types scores are assigned, enabling for measuring each element. Beforehand no validation of the level of negativity of positivity can be given; therefore the score is either +1 or -1. The Table (see Table 4) from out the dissertation of Negro (2007) is substantiated by the data of Bergek et al. (2008). By applying this method to the District Heating TIS, barriers can be revealed from out the results and by comparison of the system functioning with the proposed set of system functions for the phase of development the technology is in. The attained data for the Event History Analysis is discussed in sub-paragraph 3.4.1.

Table 3: Event types as indicators of TIS functions (adapted from van Alphen, 2011). This indicative scheme is used for the allocation of events to the system functions.

| **System functions** | **Event types** |
|---|---|
| F1. Entrepreneurial Activities | Projects with a commercial aim, demonstrations, portfolio expansions |
| F2. Knowledge Development | Studies, laboratory trials, pilots, prototypes developed |
| F3. Knowledge Diffusion | Conferences, workshops, alliances, joint ventures, platforms, branch organizations |
| F4. Guidance of the Search | Expectations, promises, policy targets, standards, research outcomes |
| F5. Market Formation | Regulations supporting niche markets, generic tax exemptions, ‘obligatory use’ |
| F6. Resource Mobilization | Subsidies, investments, infrastructure developments |
| F7. Creation of Legitimacy | Lobbies, advice |

[5] The Lexis Nexis ™ academic news archive contains all articles that have been published from 1990 onwards. The relevant articles can be found by means of a keyword search.

Table 4: Classification scheme for measuring system functions in event history analysis (adapted from Negro, 2007). This table is developed to allocate the events to system functions with addition of an evaluative score (impact).

| System Function | Event type | Score |
|---|---|---|
| F1. Entrepreneurial Activities | Project started, Patent granted | +1 |
| | Project stopped | -1 |
| F2. Knowledge Development | Desktop, Assessment, or Feasibility studies on the technology | +1 |
| | Research project stopped | -1 |
| F3. Knowledge Diffusion | Workshops, Conferences, Patent applied | +1 |
| | Lack of knowledge networks | -1 |
| F4. Guidance of the Search | Positive expectations of the technology, Government regulations | +1 |
| | Negative expectations of the technology, Expressed deficit of regulations | -1 |
| F5. Market Formation | Specific favourable tax regimes and environmental standards | +1 |
| | Expressed lack of favourable tax regimes or favourable environmental standards | -1 |
| F6. Resource Mobilization | Subsidies, investments for the technology, biomass streams or residual heat allocated to the project | +1 |
| | Expressed lack of subsidies or investments, shortage of biomass streams or residual heat allocated to project | -1 |
| F7. Creation of Legitimacy | Lobby activities for the technology, support of technology by government and industry | +1 |
| | Lobby activities against the technology, expressed lack of support by government, industry | -1 |

## 3.3 Social network analysis

Social network theory is an approach that studies social structures. Such structure is conceptually built up of 'nodes', i.e. organizations or firms (actors), and 'linkages', i.e. the connections between those nodes (Wasserman & Faust, 1994; see Figure 4 for an example). Together, the nodes and ties form a social network. The actors within the network and their actions are considered to be interdependent, rather than independent (Wasserman & Faust, 1994). The ties between actors are important channels to exchange knowledge and competences (Wasserman & Faust, 1994). In addition, the networks' structural environment is considered either a driver or a barrier from individual actor and technological perspective. Social network theory offers attractive opportunities to analyse actors and networks part of the structure of an innovation system (van Alphen, 2011). The layout of such a network – the actors and the connections between them – is termed the network structure. Social network analysis allows for studying this network structure for potential constraints or barriers, as it offers a wide range of measures that say something about the attributes of individual actors or the network as a whole. These attributes, such as the position of actors in the network or the shape of the network, can be used to get a better understanding of the network and its actors; i.e. how the network is organized, which actors are cooperating with each other, which actors are important hubs in the network, which actors are important in connecting other actors, etc.

Using the social network approach to study concepts from innovation system theory demands considerations on their conceptual compatibility. Both theoretical frameworks need to rely on the same underlying assumptions to be able to be used complimentary. This means that social network theory shares the same assumptions about *actors* and *networks* as the structural analysis of the TIS. Both theories have in common that they heavily emphasize the importance of not individual actors, but instead the interactions between these actors. An individual actor in social network theory is in itself less important than the relationships it shares with other actors in that network, just as an individual firm in the technological innovation system is just a lone wolf without many opportunities as long as it does not interact with other actors in the system. Even Hughes' (1987) prime mover or system builder needs interaction with other actors in order to be successful; at least suppliers or customers. In addition, both perspectives agree on the interdependent nature of the actors within the system. This means the importance of networks to diffuse knowledge and competences and the ability of networks to constrain or stimulate individual actors. In addition, social network theory has been used earlier in combination with the theory of innovation systems e.g. (Alphen, 2011; van Alphen et al., 2010). Using social network approach in this research as part of the TIS analysis will provide a more effective framework to study the whole of the innovation system, analysing both the structural as well as the dynamic aspects. More precisely the social network analysis answers the actor and network part of sun-question 2 and provides direction for Function 3: Knowledge diffusion, as this is not possible without the existence of networks.

Finally, the data for the social network analysis is obtained by analysing the participants in projects related to the heating technologies under study (further discussed in section 3.4.2). Possible data sources are government subsidized (pilot) projects, workgroups within trade association, and interest groups, participators in research projects, etc. The database is substantiated and verified by asking the interviewees if they can think of other possible networks and/or actors. The actors and their ties are stored in a database in the form of a network matrix. This matrix is analysed using the network analysis program 'Gephi' (Bastian et al., 2009). Central prominent actors per TIS play an important role in the system and can be identified by large nodes with numerous ties. Clusters of actors can be present, which indicates common collaborations and joint projects between them; identified by a 'cloud' of actors closely tied together. Furthermore there are connecting actors in the network. These play perhaps a 'key' role in knowledge diffusion among the present clusters. They potentially form gatekeepers within the innovation system. Actors that are only liked to one other actor or only with weak ties form the outer frontiers of the social network, but perhaps can provide complementary resources and knowledge from adjacent innovation systems.

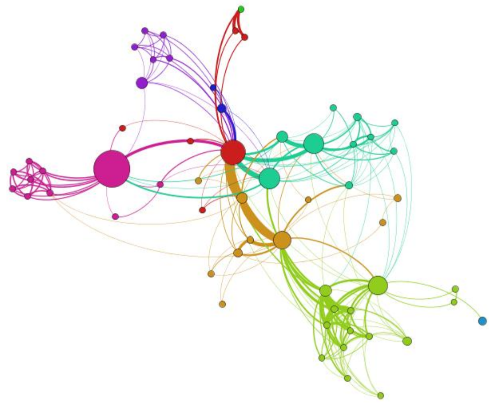

Figure 4: Example of a social network, not based on data from this research. The circles represent the individual nodes and the curves the linkages between them. The size of both represents the number of occurrences and the colouring indicates different sub-sets within the network (Bastian et al., 2009).

### 3.4 Data acquisition and analysis

The data acquired in the course of this research cover various sources and source types. As elaborated in the previous paragraphs both qualitative as quantitative methods are applied. In the upcoming sub-paragraphs the empirical data gathered in search for answering the research question is presented and discussed. For each data type it is set forth, which method it provides the input to.

#### 3.4.1 Interviews

To contemplate deep understanding of the innovation systems of DH and BG expert interviews were conducted. These also are input for the completion of the project databases and validation of preliminary results. In total twenty-two interviews were held with experts from different positions in the Dutch heat sector. There were interviews with people overviewing both systems as well as interviews with technology specific experts. The interviewees were mostly covering DH or BG. Five experts interviewed were consulted on both technologies and consequently impact the analysis of each. Consulting interviewees that overview both systems reduces the possible bias against a specific technology. The conducted interviews resulted into thirteen interviews impacting the District heating analysis and fourteen interviews that affect the BG study. The interviewees are presented anonymously because of privacy reasons and abstracted to their work title (See Appendix 11.1 for a list of the topics and the work titles). For the BG analysis an additional data source is utilised. The data of eighteen interviews with potential biogas producers, conducted by a party external to this research, is taken to further sufficient the functional analysis of the BioGrid development.

#### 3.4.2 Project data

The project data is the input for the social network analysis. This data is gathered by contacting institutions that are related to the heat sector, for example NL Agency [6] and the Dutch Authority for Consumers & Markets (ACM, previously NMA). The network visualisation and analysis is performed using 'Gephi' as described earlier. From out the databases from NL Agency and ACM a project file consisting of all BG and DH project and related actors is created. The database is validates by consulting experts that actively operate in the field of either BG or DH. This is the input for the social network analysis for this technological system. The social network analysis impacts the structural analysis with respect to the actors and their possible network and the functions Entrepreneurial Activities (F1) and Knowledge Diffusion (F3).

#### 3.4.1 Lexis Nexis and Literature

For the Event History Analysis (see section 3.2) of the District heating innovation system data extracted from Lexis Nexis is used. The data comprises of a total of 1068 Dutch national newspaper articles and 66 trade magazine articles ranging from 1990 until 2012. Extracted by use of the 'power search' function in which a multi search term option is utilized. This ensures that the extracted articles cover the technology (LexisNexis, 2012). Nevertheless, there are still articles that are not in the scope of this research; for example, an article on the regulatory system of DH in Moscow. After in-depth reading of the articles, the actual used data for the event history analysis consisted of 646 newspaper articles and 46 magazine articles. The acquired articles for 2013 were used to practice

---

[6] NL Agency (Dutch: AgentschapNL) is a division of the Dutch Ministry of Economic Affairs that supports sustainable joint initiatives in the Netherlands, developing countries, and emerging markets.

the Event History Analysis method. All articles are analysed contra-chronologically, thus from 2012 up until 1990. How the event history articles are divided over the years is presented in Figure 10. In this graph also a dip in available articles is visible from 2001 to 2004. This needs to be taken into account when further analysing the data and formulating results. For the literature review a literature search has been performed resulting in articles that cover or hint towards barriers to the development of District Heating systems in general or infrastructural energy technologies. Some of the barriers might also apply to the BioGrid technology; this is further delved into in the analysis, Chapter 6.

## 3.5 The TIS analysis and results

From the above discussed methods and data the TIS analysis is performed. The results are presented per technological innovation system in Chapter 4 for BioGrid and Chapter 5 for District Heating. In Figure 5 an overview of the empirical data, the applied research methods, and upcoming results is provided. An overarching analysis of the results and emerging barriers to TIS development is provided in chapter 6.

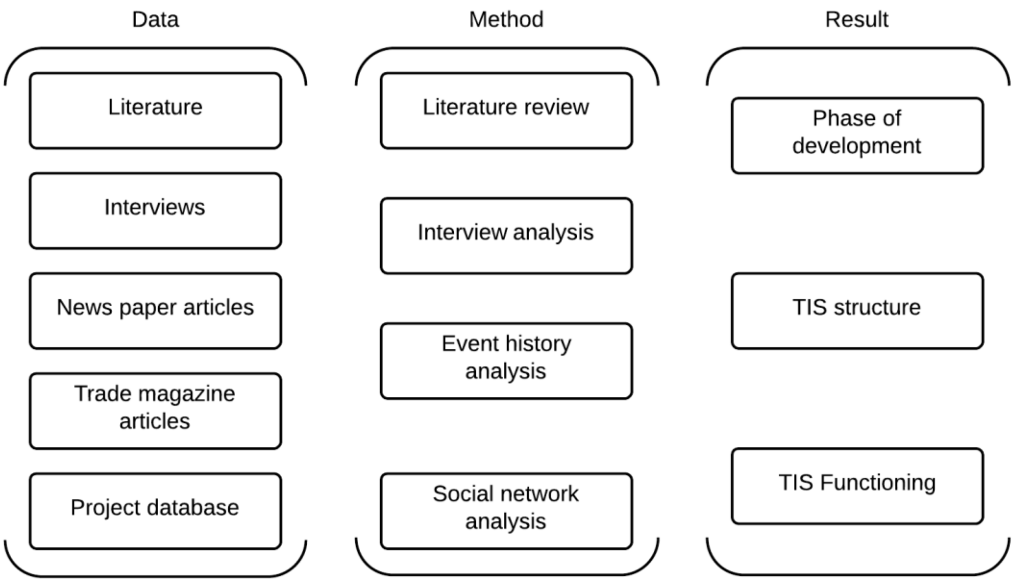


Figure 5: Overview of the data and methods used in this research and the upcoming results presented in this thesis in Chapter 4 and 5. These are elaborated on in the above paragraphs of Chapter 3.

# 4. Results: the BioGrid innovation system

The results for the phase of development, structure, and functioning of the BioGrid innovation system following from the assessed data are presented in this chapter. These results answer the sub-questions for the BioGrid. An analysis of the results of BG and DH is presented in Chapter 6.

## 4.1 The BioGrid concept

The BioGrid is an infrastructural system transporting Biogas (see Figure 6); it enables the direct usage of biogas in household appliances. It is a technical system in which gas of variable methane quality can be distributed among users connected to this grid. In some cases a large/industrial user (for example a paper mill or other firm that has a large and steady heat demand) can be included in the infrastructural system to guarantee a base consumption level and thereby reduce the necessity of biogas storage. In line with preliminary findings on the development phase of the BioGrid TIS, interviewees indicate that the phase of development in the Netherlands is between the Pre-development and Development phase (Project Manager, 14-2-2013; Product Developer, 6-2-2013; Manager R&D, 7-3-2013). There are working pilots, however full a functional commercial application of a complete BioGrid is still in design. In the final stage of this research a demonstration event is held at the Eerbeek pilot site (Alliander, 2013) and an article was written about it in 'Technisch Weekblad' (2013), this is an indication of efforts to improve Market Formation (F5) and the Creation of Legitimacy (F7). Due to several factors, i.e. difficulties in the alignment of stakeholders and search for a first commercial site (Product Developer, 6-2-2013; Innovation Manager, 14-3-2013), the BG innovation system has not yet entered the Development phase yet.

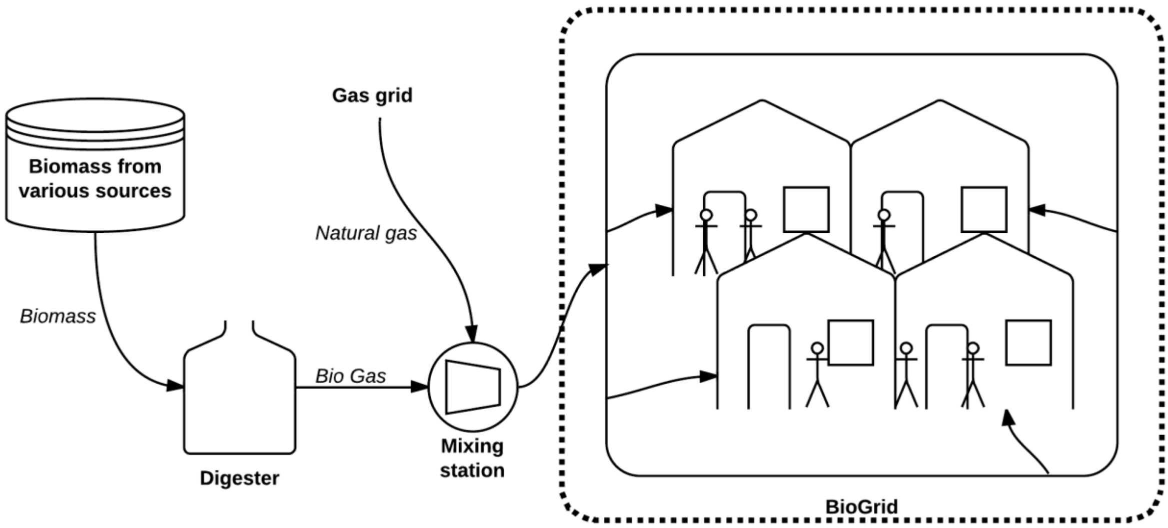


Figure 6: Schematic representation of a simplified BioGrid system. The figure represents the value chain from production until end/consumer. Depending on the usage and production a mixing station is included to ascertain the availability of gas to the consumer. Biomass from various sources is digested into biogas and residual materials. The biogas is transported via pipeline to a mixing station where depending on quality natural gas from the gas grid is added and mixed. After the mixing stations and quality measurements the gas is distributed over the BioGrid among the connected consumers. The arrows are indicative for the flow direction and hint towards the grid layout.

## 4.2 BioGrid innovation system structure

The structure of an innovation system consists of institutions, actors, and networks. The interaction and interplay between these system factors is important for the development of the innovation system (Musiolik et al., 2012). The existence of networks is a premise for the distribution of knowledge and resources over the sector (Jacobsson & Johnson, 2000). In the upcoming sub-paragraphs the actors and networks and the overarching institutions are discussed. First, an elaboration of the emergence of the BioGrid concept is presented to provide an overview of the emergence of the innovation system and put the current innovation system structure and functioning in perspective.

The BioGrid concept is developed within the grid company Alliander (Latta & Hardi, 2009). Paul Latta was the conceptual founding father of this infrastructural energy concept (Innovation Manager, 14-3-2013). Preliminary developments around the direct use of biogas started as early as 1998 from out KIWA, however not yet included consumer applications. Such first steps were taken by a technical firm called LowCONOx that thought out and engineered the possibility of using a broader Wobbe Index[7] in gas condensing boilers. The system consisted of carbon monoxide concentration measurements and regulation of the oxygen supply to the burner. Later on TNO and OOST developed a different but similar concept also enabling a broader caloric gas mix as energy source for boilers. In 2008, the grid company Alliander coupled such consumer appliance with the direct dispersion of biogas in a grid separate to the natural gas grid. This had led to the coining of the BioGrid concept. In 2009, further technical and regulatory assessments were made on the BioGrid (Latta & Hardi, 2009). Alliander’s CEO Peter Molengraaf in 2010 presented the BioGrid at a KIWA conference; this was the introduction of the concept to a broader public. In the summer of 2010 the BioGrid was first tested. At that time the conceptual creator of the BioGrid retired from Alliander. An innovation manager at the strategy department took over the portfolio and further innovated on the concept. A formal collaboration with ATAG heating was formed. Alliander together with ATAG backed by smaller technical firms, applied for a subsidy for the development of a multi-gas boiler product (essential for the success of and even testing of the BioGrid concept). This subsidy is actually based on a green gas subsidy tender, as the regulatory and subsidy framework did not support this peculiar kind of projects. Part of this subsidy is an obligation to commercially test the system at a scale of 200 households.

At the moment there is no Biogas standard yet. To nevertheless ensure safety ATAG developed an output measurement (Manager R&D, 7-3-2013). A gas grid norm change or biogas standard (perhaps bandwidth) is needed to include the BioGrid and even biogas in the gas law (Latta & Hardi, 2009). Question remains, how sustainable and environmental friendly is biogas actually (Independent Expert, 3-4-2013; NEN, 2011; van Wolferen et al., 2013). The interpretation of the regulations and laws in the Netherlands remains questionable as green gas and biogas are treated as somewhat the same and inter-exchangeable in some reports. At the moment there are no generally accepted EPC calculations for the BioGrid system, this is this in development and there are difficulties in how to grade the potential varying of the biogas mixture with natural gas (Product Developer, 6-2-2013;

[7] The Wobbe Index is used to compare the combustion energy output of different composition fuel gases in an appliance. This index is an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and biogas and is frequently defined in the specifications of gas supply companies and gas grid operators.

Senior Network Strategist, 11-2-2013; Independent Expert, 3-4-2013). Claims of an EPC of 0.3 have been made, that is matching with the 2016/2017 norms. Further improvements have to be made to match the upcoming requirements; otherwise the technology will become not an option for future new housing after 2018.

### 4.2.1 Actors and Networks

Actors in the BioGrid heat innovation system are strongly related to the present three pilot projects (Project Manager, 14-2-2013; Gas Consultant, 19-2-2013). The BioGrid concept was developed within the Dutch grid company Alliander and all the projects are somehow linked to this firm (see Figure 7). The consumer heating appliances capable of burning varying caloric values, important for the direct use of biogas was developed by ATAG heating in alliance with Alliander. Sub-contractors to ATAG provided important technology for the Multi-gas boiler. Currently three pilot sites are running or in planning in the towns Eerbeek, Dronten, and Neerijnen (Alliander, 2013). A fourth project in the scope of BioGrid is in design phase (Gas Consultant, 19-2-2013; Policy Advisor, 21-1-2013) and is added to the network analysis. This project entails sewage gas extraction and usage in an apartment block. At this moment Alliander is negotiating current sewage regulations with the Ministry of Home Affairs for the implementation of an exceptional position (Gas Consultant, 19-2-2013). In the Netherlands it is forbidden to ad vegetable, fruit, and garden waste to the sewage system. The addition of this biomass is needed to supplement the 'sewage biogas' production.

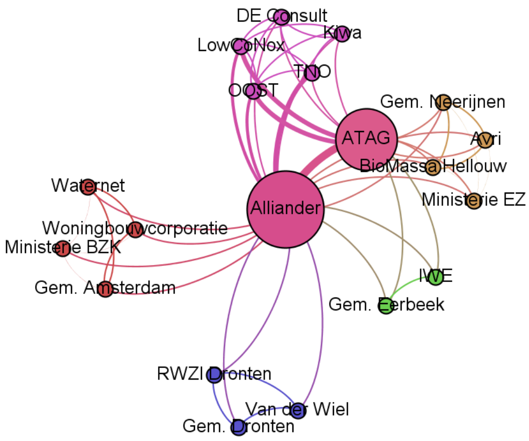


Figure 7: graphic representation of the network for BioGrid, created with the network analysis software 'Gephi' (Bastian et al., 2009). The colouring is done using the 'neighbour'-function that colours nodes within one direct network. Alliander and ATAG are central in this network and show the most 'interaction' for the utilised dataset. The line thickness represents the relative number of system interactions between actors. The size of the nodes represents the relative number of occurrences of the actor in the system (for large version see Appendix 11.7).

Alliander and ATAG are prominently present in the BioGrid network created from project data (see Figure 7). Coupling the current projects with the corresponding actors generated the basis for this network visualisation (see Appendix 11.3). The software program 'Gephi' was used to generate the image (Bastian et al., 2009). At this early stage of TIS development the search for new potential actors in the sector is crucial. This ensures system growth and enhances the likelihood of technology adoption by project developers in the design of new neighbourhoods. This is essential for the commercial application of the BioGrid (Product Developer, 6-2-2013). At the moment, there are limited new housing projects due to the financial conditions of the general Dutch economy and building sector. Actors with strong ties to the building sector and government are potentially needed to further develop the system and increase the likelihood of finding a first commercial site. The BG network needs to be enlarged and perhaps biogas lobby parties can be included to raise the awareness of the technology among general public.

### 4.2.2 Institutions

The institutional framework for the BioGrid is not clearly defined as the technological system is in between the pre-development and development phase. Therefore the institutional arrangement largely relies on that of the adjacent natural gas and green gas innovation systems. For these institutional arrangements such as subsidies and specific regulations have been formed. In the Netherlands green gas is part of the ‘gas law’, biogas is not (yet) included in this operational law. Hence, the market structure at this point is highly worked around existing regulatory frameworks from adjacent sectors, such as the natural gas sector and more profoundly lobby activities of biogas and biogas platforms. More concretely the EPC is going to impact the BG innovation system. Depending on how government is going to grade the use of biogas as a domestic heat source in the EPC calculation it is a restraint or a helping factor (Independent Expert, 3-4-2013; NEN, 2011; van Wolferen et al., 2013). The $CO_2$-emission reduction targets of municipalities will help the BioGrid development. At this moment no concrete measures have been taken by the ACM or NL Agency on how to include BioGrid in their portfolio. NL Agency has created a platform where the biogas potential of the Netherlands is overview. This platform is called the Heat Atlas, such information openness by Dutch institutions favours BG development (see for example Appendix 11.14). However, this is not further specified for BioGrid and a concrete regulatory system around BioGrid has yet to be built up.

## 4.3 BioGrid innovation system functioning

This paragraph contains an elaboration of the results per TIS function; extracted from expert interviews, interview data from potential biogas producers, and literature review. According to the current phase of development of the BioGrid innovation system – in-between the Pre-development and Development phase – the functions knowledge development (F2), knowledge diffusion (F3), resource mobilisation (F6), and guidance of the search (F4) are important (See Figure 3). At this point in the development the emphasize remains with knowledge creation (F2). In order to move into the next phase the functions entrepreneurial activities (F1), market creation (F5), and counteracting resistance to change (F7) become more into place. The move towards the better functioning of other functions, and thereby the innovation system, requires dynamic capabilities of the actors operating in the field. For example, other project management skills are required when developing a pilot project or demonstration site, than when there are multiple large-scale commercial projects to roll out. The TIS functions are elaborated on in order of occurrence similar to section 2.4 (Hekkert et al., 2007).

Overall the BioGrid technology development is relatively successful compared to the tempo of technological change in the gas sector (Junginger et al., 2010). However, concrete steps are needed for the identification and roll out of the first large site (Innovation Manager, 14-3-2013). This will form a crucial stage in the growth of the BioGrid Innovation system. An analysis of the interaction of the innovation system structure and functions linked to the systemic problem framework towards the identification of barriers, coupled with the DH results, is provided in Chapter 6.

**F1. Entrepreneurial Activities** – Innovation withholds great uncertainty in whether a technology fails or is successful. Entrepreneurial actors have the important task to experiment with new technologies and their applications (Hekkert et al., 2007). The central player in the actor network, Alliander (see Figure 7), is currently operating three pilot sites and organised a formal opening of a demonstration site (Alliander, 2013). Such projects positively impact the Entrepreneurial Activities Function; however concrete entrepreneurial steps to the creation of the first large BioGrid need to be taken. The large costs of the first large BioGrid projects forms a barrier (Product Developer, 6-2-2013; Consultant, 12-3-2013). When looking at the biogas market, which impacts the BioGrid TIS, there is a shakeout of SME firms. Various biogas production technologies have been tried and numerous biogas projects have been stopped due to ending in financial streams; from for example subsidies or decrease in actual production versus the formed business case (Independent Expert, 31-1-2013). There is actually a decrease in biogas production visible in the Netherlands over the last decade (Gas Consultant, 19-2-2013). Currently the viability of a BioGrid in practice remains uncertain due to a lack in practical knowledge and learning by doing (Process Manager, 13-3-2013). This is further impaired by the limited amount of new housing projects in the current market; currently renovation projects are not in the scope of a potential first commercial site (Product Developer, 6-2-2013). The revenue model of BioGrid is not fully crystallized yet (Product Developer, 6-2-2013). However, at the moment no other parties are developing a similar technology with household appliances (Product Developer, 6-2-2013; Manager R&D, 7-3-2013). From a consumer perspective the BioGrid is now only applicable to domestic heating; other appliances, such as gas stoves, need to be developed (Senior Network Strategist, 11-2-2013). The availability of a broader portfolio of appliances will stimulate this function positively.

**F2. Knowledge Development (Learning)** – Knowledge development is and important process in each TIS, especially in the early phases. The knowledge development for BG technology is mostly performed intra firm, however alliances with knowledge institutes are formed, for example between TNO and Alliander. For the multi-gas boiler development an alliance was formed between ATAG and Alliander in cooperation with smaller technology suppliers. Concrete collaboration with research institutes and Universities is sought to study particular parts of the BioGrid value chain (Product Developer, 6-2-2013). There are projects on actor involvement, model building, and other related issues but the actual technology is more a market party matter. Nevertheless, the EDGAR program provides a platform in for technology development in cooperation between universities and companies (Senior Network Strategist, 11-2-2013; Gas Consultant, 19-2-2013). At the moment a patent is in application specific for the biogas cleaning process technology in the BioGrid (Product Developer, 6-2-2013). A final potential arising issue indicated by interviewees is the enthusiasm of technical workers for BioGrid might be difficult and a skewed prioritizing of budgets might hamper the knowledge creation (Project Manager, 14-2-2013).

**F3. Knowledge Diffusion (Through Networks)** – The developed BioGrid knowledge and information (created when F2 performs properly) can only be used efficiently when diffused among the TIS actors in order to properly apply the knowhow. Given the relative novel phase of development of the BioGrid innovation system knowledge diffusion still is possible through informal contacts and individual interaction. At the moment there are no specific platforms for BioGrid technology. The phase of development of the innovation system does not call for such mechanism to arise yet, however this could speed up the process of interaction with potential investors and other necessary actors in the innovation system. In addition, knowledge diffusion to potential new BG innovation system actors is important to further enlarge the system. Knowledge on how to validate this system lacks in the heat sector, reaching out to other actors will be crucial when striving to further strengthen the innovation system (Product Developer, 6-2-2013). Knowledge diffusion within the BioGrid network is project based. The strongest collaboration is between Alliander and ATAG (Senior Network Strategist, 11-2-2013). Overall this function needs to perform better in order to strengthen the growth of the BioGrid innovation system and allow others to understand what the technology entails.

**F4. Guidance (of the Search)** – The guidance that springs from vision documents by for example the International Energy Agency the potential impact of Biogas on the transition towards a sustainable heating system is often overlooked. The BioGrid does not fit in the current laws and regulations concerning gas technologies and gas grid management (Senior Network Strategist, 11-2-2013). When assessing documents from the Dutch government, one can draw the conclusion that politics struggles to get grip on the actual environmental friendliness of biogas (Integral Energy Consultant, 5-3-2013; Independent Expert, 3-4-2013). The government's vision on how to use and/or transport this mode of energy is even less clear (Independent Expert, 3-4-2013). However, when BioGrid has a formal impact on the EPC norm, a powerful driving force is in favour of BioGrid development will be present. When compared to a similar house with gas condensing boiler burning natural gas the BioGrid will result in a lower EPC (Independent Expert, 3-4-2013). Green gas was one of the first sustainable gas options that the Dutch government looked into (Gas Consultant, 19-2-2013). Supported by the incumbent gas firms the technology was heavily subsidised and golden mountains were promised to potential producers (Manager R&D, 7-3-2013). The BioGrid concept builds on this idea of improving the sustainability of the gas sector however utilises biogas directly. To this point no direct BioGrid subsidy is formed, only as a subsidiary from the green gas subsidies, where advantage is taken from the unclear definition of biogas and green gas in Dutch regulations. Expectations of potential users and biogas producers vary and some even indicate to have ethical problems with the use of food like biomass for the production of biogas; even if this is not human food grade. The expectations from governmental point of view are not yet fully developed, as they are not certain what to expect from a BioGrid system. This creates an influx in which parties are mutually waiting for a first mover. Luckily Alliander is an actor that created a first move with the Eerbeek concept demonstration plant (Alliander, 2013). This has the potential to open up the discussion for concrete guidance from governmental agencies.

**F5. Market Formation** – *"A new technology often has difficulty to compete with embedded technologies"* (Hekkert et al., 2007, pp.424). In order to allow the technology to be commercialised and further refine the technology complex specific market conditions can be created. The formation of alliances and partnerships is in this preliminary phase of innovation system development mostly project driven (Musiolik et al., 2012). This is visible in the network build-up of the BioGrid innovation system (see Figure 7). The contact with municipality governments is crucial to shorten permit applications and create legitimacy in the region (Project Manager, 14-2-2013). The prime mover Alliander has historically bounds with all government levels in the regions it operates in. Provinces as shareholders of the firm and municipality as stakeholders in the societal goals Alliander strives for (Alliander, 2012). At the moment the Dutch government is still obliged towards cogeneration and green gas projects (Integral Energy Consultant, 5-3-2013; Independent Expert, 3-4-2013). At some points these projects are conflicting with potential biogas production and BioGrid sites. Especially the green gas tenders are conflicting as there the produced biogas is upgraded towards gas grid standard and the direct usage in a BioGrid becomes out of the scope of the business case. On the other hand is the potential market size of a green gas installation larger, compared to a BioGrid. A BioGrid is limited to a specific hinterland. A method for calculating the usage per household is not yet fully functional for the BioGrid, as this is not merely volumetric due to the varying Wobbe Index of the consumed gas. There are thoughts on how to arrange this, but no concrete billing scheme has been formulated (Senior Network Strategist, 11-02-2013). Overall, the market structure is not in favour of new technologies and inclined to point towards existing standards and methods.

**F6. Resource Mobilization** – Resources form an important input, as all other TIS Functions require some kind of resource availability in order to function properly (Hekkert et al., 2007). The financial crisis has impact on the availability of monetary resources. However, contrary to what one would expect there is an abundance of funds available for sustainable energy project, especially when a stable partner is managing the project and barring the risk (Senior Bid manager, 6-2-2013; Innovation Manager, 14-3-2013). One of the BG projects was partly subsidized by a subsidy from out a Green Gas subsidy scheme. At present no specific BioGrid subsidy is formed, however some environmental friendly subsidies might be applicable to the technology, for example the SDE+. The mobilisation of resources at this point is not the function that plays to most important role. However, financial resources are needed to overcome initial investments when engineering a new kind of infrastructural energy technology (Innovation Manager, 14-3-2013). More profoundly, entrepreneurial action is needed to overcome the risk aversion in the system. When assessing the interviews with potential biogas producers (mostly farmers) it became clear that there is a negative tendency towards the organisational risks associated with biogas production. Some even indicated to have ethical issues with food sources (even when not for consumption) were used for the production of biogas. In their answers the farmers linked the BioGrid concept back to the green gas and co-digestion projects. Over the past years they had negative experiences with market parties that offered them such technology. This impacts the BioGrid development in the sense that the farmer producer is unlikely to participate in such endeavour; resulting in difficulties to find proper biogas resources. The farmers indicated that there are ethical reasons not to use food related biomass for the production of biogas as well as that they want to stick more to their core business instead of becoming a gas producing company. For other sources of biogas such issue is less profoundly present. Sewage treating plants therefore form a potentially ideal stepping stone as for a first mover project. Generally, there is a decline in the Biogas production from municipal waste and sewage treating plants (Senior Network Strategist, 11-2-2013). At the moment the value chain is not coherent. All parties are working on separate business cases and not necessarily working together. Value chain actor alignment is crucial of BioGrid development. Cherry picking needs to be stopped and risks divided among parties that can bare it (Project Manager, 14-2-2013). A difficulty for BG is the large upfront investment. Not only for the BG infrastructure but also for other parts of the system, for example the biomass digester. Providing biogas producers with service contracts on the technology perhaps enables a more swift dispersion of the BG as a whole (Manager R&D, 7-3-2013).

**F7. Creation of Legitimacy/ Counteracting Resistance to Change** - The only legitimacy issue faced by BioGrid are felt at the consumer side. Calculation of a fair price and the billing of the consumed biogas form a challenge (Technical Trainee, 18-3-2013). In addition to that, 'Freedom of choice' is a strong force within the Dutch energy market (Consultant, 12-3-2013). Consumers tend to favour the existing market and what they are used to, however when moving to an area where such grid is located no negative impact is indicated. The standardisation and safety measurements on the multi-gas boiler are not yet fully operationalized (Manager R&D, 7-3-2013). These measures are formed from out the current natural gas system and for a potential barrier to the commercial application of the technology. At present, formal lobby comities or technology platforms are not yet formed and could improve the functioning of F7.

# 5. Results: the District Heating innovation system

The results for the phase of development, structure, and functioning of the District heating innovation system that follow from the previously discussed data are elaborated on in this chapter.

## 5.1 The District Heating concept

District Heating is a technical system for the distribution of heat (see Figure 8). The heat is often generated in a central location and distributed towards residential and commercial consumers. In other words, DH is an infrastructural system for the transportation of heat in water trough pipelines. Figure 8 provides a schematic representation of the constellation of a District Heating system, with some explanation on the system working. The phase of development of DH in the Netherlands is at first sight not straightforward. The premise of existence of a commercial application is met, however the criterion of fast market increase has never been met, nevertheless did the DH technology somewhat stabilize over time. From this information one would perhaps chose the Acceleration phase. However, given the current developments with geothermal heat and the technology push by amongst others the municipality of Amsterdam (Nieuwsbank, 2013) the actual position of DH is in the Take-off phase. Several experts added to this that perhaps the residual technology from out electricity plants has already reached the Acceleration phase. The remainder of this research adopts the stand that the DH innovation system is in between the Take-off and Acceleration phase, but mostly shows system features of the Take-off phase.

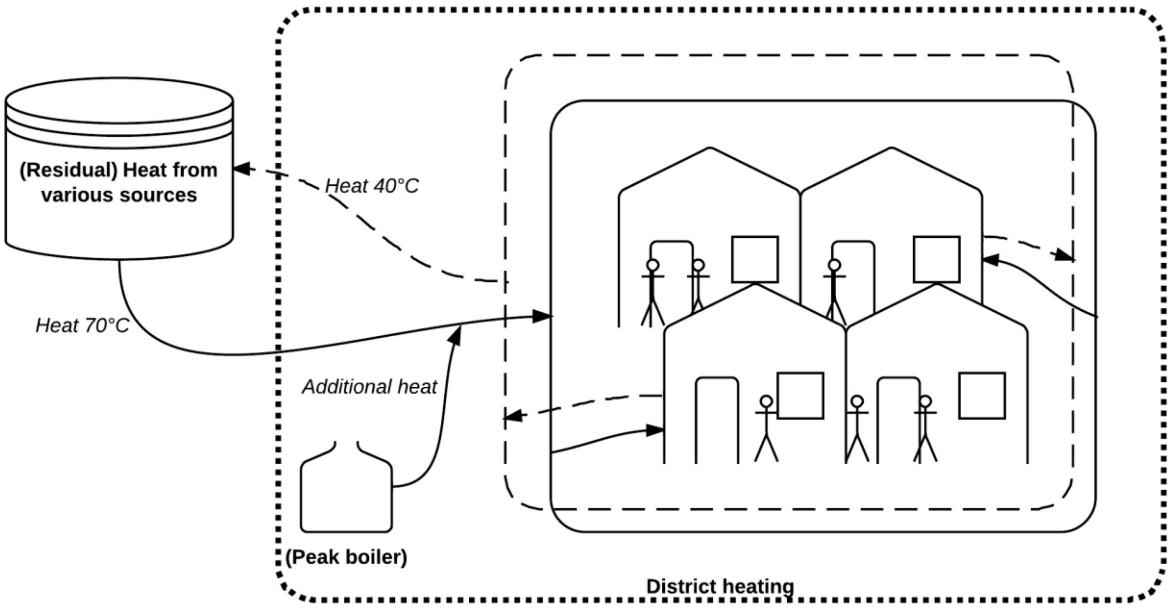


Figure 8: Schematic representation of a simplified District Heating system with inclusion of a peak boiler. The peak boiler can be added for example for security of supply or temperature control. The heat source can be from various sources such as a residual stream from industry or power plants or an autonomous heat source; for example geothermal or seasonal storage. The arrows are indicative for the flow direction and hint towards the grid layout. A DH system is most often a two directional system. The heat streams and temperatures serve as an example and vary among District Heating setup.

Interviewees indicated that DH never really made it to the acceleration phase and somewhat remained stuck in between the take-off and acceleration phase (Project and Process Manager, 8-4-2013; Senior Policy Advisor, 12-2-2013; Strategy Consultant, 6-2-2013). Since the last decade DH began to attract attention as an ‘easy’ method for reaching $CO_2$-emission reduction targets (Strategy Consultant, 6-2-2013). Some interviewees indicated that the gas condensing boiler is a very competitive heating technology compared to DH due to the fine dispersion of the Dutch natural gas grid and that only under specific conditions DH is more favourable (Senior Policy Advisor, 12-2-2013; Technical Specialist Heat, 25-2-2013), amongst others the availability of ‘cheap’ heat streams, new (to be) built neighbourhoods, strong incentive from the municipality and large distribution area (over 500 households; Senior Policy Advisor, 12-2-2013; Technical Specialist Heat, 25-2-2013; Strategy Consultant, 6-2-2013). In the remainder of this chapter the results of the system structure and system functioning are presented

## 5.2 District Heating innovation system structure

The structure of an innovation system consists of institutions, actors and networks. The relation and interaction between system factors is important for the development of the innovation system (Musiolik et al., 2012). The existence of networks is a premise for the distribution of knowledge and resources over the sector (Jacobsson & Johnson, 2000). In the upcoming sub-paragraphs the actors and networks and the overarching institutions within the District Heating TIS are discussed. Thereafter, the system functioning is discussed in accordance of the seven TIS functions.

### 5.2.1 Actors and Networks

The actors and networks for district heating presented in this thesis are based on various data sources; expert interviews, literature review, and project data. The project data in particular is used as basis for the social network analysis. The data is gathered with care, however is possibly not exhaustive. Nevertheless the social network analysis does provide, based on the project data, an indication what the network for DH in the Netherlands looks like. One can imagine that there might be more actors, however the larges parties and strongest ties will not deviate much. In Appendix 11.5 an overview table is provided of the DH actors. In Appendix 11.6 the DH projects are matched with the corresponding actors. This list can be further supplemented, however is sufficient for the goal of this research. Traditionally municipalities have strong ties with the district heating projects in their cities. Since the splitting of energy production and grid companies the heating portfolio remained within the energy corporations; such as Nuon, Essent, and Eneco. Over a period of time these companies were negotiating that when they were going to operate as free market enterprises certain environmental friendly projects – according to them initiated and imposed by national government – were bailed out. Such ‘brick’ projects (as they were called) provided a negative glare on district heating projects.

The existence of a formal network enhances the chance that the system will develop further (Musiolik et al., 2012). For DH in the Netherlands there is such formal network. Warmtenetwerk is an organization for the promotion of DH and central to their mission is the increase of the use of residual heat in the Netherlands and Flemish Belgium. This networking and lobby institute was started since 2008, many organisations active in the DH field are represented, however it remains uncertain how strong the bargain power of this organisation is. Nevertheless, Warmtenetwerk provides a positive voice in Dutch media on District heating and adjacent technologies, such as cold and thermal energy storage.

Looking at the DH social network created by use of project data (see Figure 9). Two large actor clusters are visible. One built around Nuon and Eneco and a second around Essent and daughter firms. Especially the actors in between these two clusters might play an important role in the further development of DH in the Netherlands. Sadly one of the connecting actors Nacap is bankrupt without restart, former competitors overtake maintenance activities. Insight in collaborations in for example Warmtenetwerk could enlighten the knowledge diffusion among DH actors. A small cluster of three actors is also visible, probably in real life connected by one of the contractor and project development firms, such as VSH and A. Hak. At this moment it is unclear what role national government plays in this network. Perhaps a knowledge division role would be suitable.

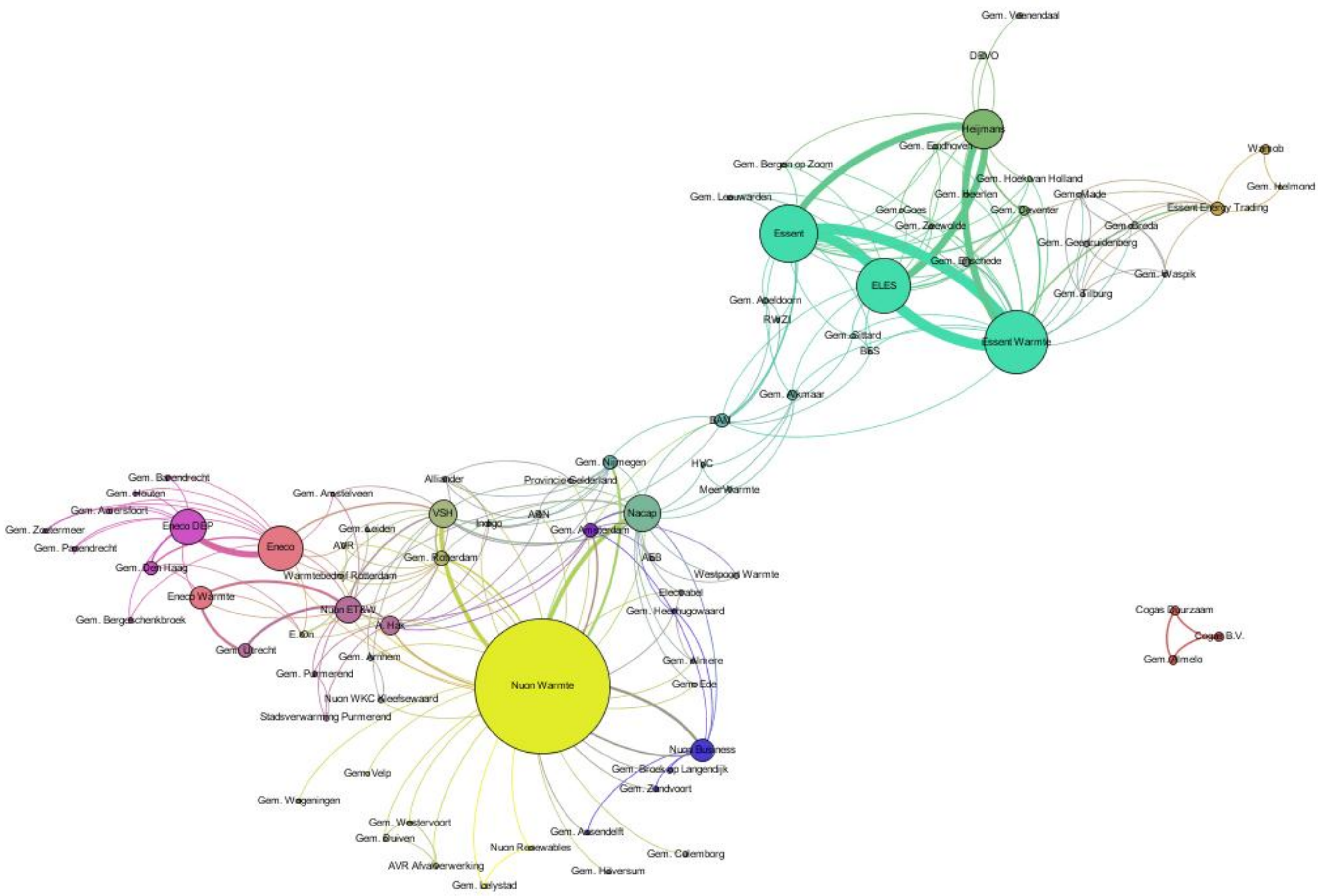


Figure 9: graphic representation of the network for District heating projects in the Netherlands. The software program 'Gephi' was used to generate the image (Bastian et al., 2009). The colouring is done using the 'neighbour'-function, which colours nodes within one direct network (a larger version of this network is provided in Appendix 11.7). The line thickness represents the relative system interactions between actors. The size of the nodes represents the relative number of occurrences of the actor in the system.

### 5.2.1 Institutions

The institutions are laws, regulations, policies, and sectorial normative structures that guide and limit actor behaviour. In the Netherlands the alternative (the gas condensing boiler) has a strong historical grounding in society (Strategy Consultant, 6-2-2013). For District heating the Dutch heat law in particular is important from an institutional point of view. Other that the already in the 90s implemented gas law and electricity law, the heat law (Dutch: warmtewet) is still not fully implemented. For years there has been debate in parliament on various parts of this law. Most profoundly does the part about 'niet meer dan anders' (from Dutch: not more that otherwise) impact the district heating projects business cases. Concretely this means that for a home not more than the costs it would have when heated with natural gas in a condensing boiler are allowed to be billed for the heat consumption. Due to the difficulty in supplying calculations for the theoretical gas consumption and critiques by market parties this law has been postponed multiple times. With the heat law in the making difficulties will arise for District Heating. Central in the heat law is the 'not more than other'-principle, by which district heating may not be more costly than a comparable gas heating installation for the same house. Hereby, district heating may have a problem competing with gas condensing boilers, and even more profoundly, the profitability of the business case suffers from a decrease in the gas price (Technical Specialist Heat, 25-2-2013). The heat law activation has been postponed for a couple of times with current implementation date begin 1 January 2014. Legal aspects of a local monopoly are important, this perhaps does not fit the operational style of the traditional DH firms such as Nuon and Essent (Senior Policy Advisor, 12-2-2013). Normalizing connecting fees for DH might be a solution; this needs to be operationalized by for example the ACM (Technical Specialist Heat, 25-2-2013). In striving to reach European $CO_2$-emission reduction targets municipalities more often stand willing against district heating as it helps them in achieving their $CO_2$-emission goals. The EPC specific to District Heating is not straight forwards and largely depends on the heat source and system layout (NEN, 2011; van Wolferen et al., 2013). For example a higher EPC is calculated when a peak boiler that utilizes fossil fuels is included (NEN, 2012). A lower EPC for DH will result in a longer applicability. Theoretically an EPC of 0.1 can be reached, if for example geothermal is applied with a load management system instead of a peak boiler (Technical Specialist Heat, 25-2-2013).

## 5.3 District Heating innovation system functioning

This paragraph contains an elaboration on the TIS functions for District Heating, extracted from expert interviews, Event History Analysis, and literature review. According to the current phase of development of the District Heating innovation system – at the verge of the Acceleration phase – the functions Entrepreneurial Activities (F1), Guidance of the Search (F4), Market Creation (F5), Resource Mobilisation (F6), and Creation of Legitimacy (F7) are of importance (See Figure 3). At this point in the innovation system development the accent remains is strongly on Entrepreneurial Activities (F1) and Creation of Legitimacy (F7). In order to move into the next phase the functions Entrepreneurial Activities (F1), Market Formation (F5), and Resource Mobilisation (F6) are more important. The better functioning of other functions and therefore the innovation system required dynamic capabilities and flexibility of the actors operating in the field. For example, other project management skills are required when developing a pilot project or demonstration site, than when there are multiple large-scale commercial projects to roll out. The TIS functions are elaborated on in order of occurrence in literature and similar to section 2.4 (Hekkert et al., 2007).

The results in this section are built on the Event History Analysis as discussed in section 3.2. The three figures below show indicative results. Larger versions of these graphs are provided in Appendix 11.9 & 11.10. Figure 10 shows a bar graph of the analysed articles on District Heating from 1990 until 2012. The light grey bars indicate the number of found articles and the dark grey represent the actual used articles. A dip in the number of articles occurred in the period 2001-2004, perhaps due to issues around the privatisation of the energy companies a ‘radio silence’ was agreed on. In Figure 11 the results for the Function Guidance of the Search are presented (the other Functions can be found in Appendix 11.9). There is a balance in the positive and negative events occurring from the data.

The cumulative graph of the Event History Analysis (Figure 12) provides additional insight in the development of the Functions over time. From the graph it becomes clear that especially function 7 and function 4 show to be developing negatively over the years. Both are important functions in the take-off phase and even in the acceleration phase both are still of meaning. Knowledge Development (F2) and Entrepreneurial Activities (F1) are performing relatively well. Nevertheless, when the knowledge is not diffused innovation system development might be hampered. Important is that when moving from the take-off phase towards the acceleration phase the innovation focus moves from explorative towards more exploitative nature. In other words, there is a shift towards efficiency instead of new idea creation. The District Heating innovation system as a whole seems to function not particularly well for the larger heating systems, improvements can be made. Smaller and future networks face challenges. These challenges are overviewed in Chapter 6. Where an analysis of the interaction of the innovation system structure and functions linked to the systemic problem framework towards the identification of barriers, coupled with the BG results, is presented.

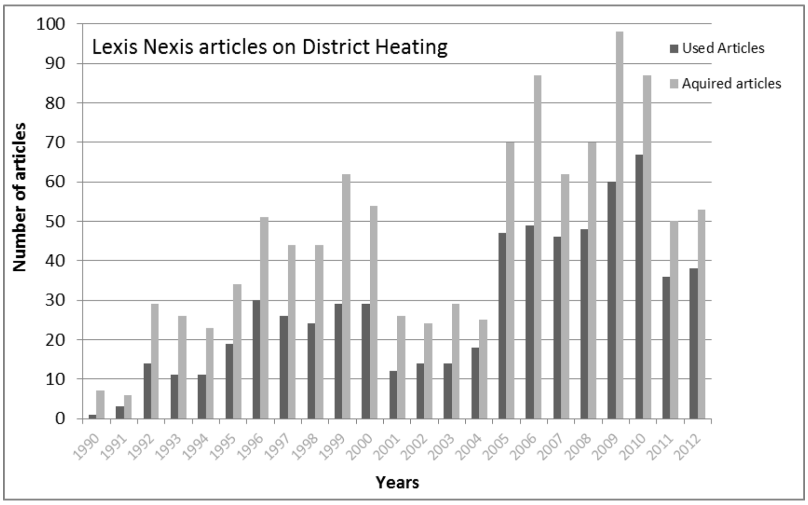


Figure 10: Bar graph on the number acquired articles in the Lexis Nexis search (see section 3.2 and 3.4.1) and the number of articles actually used in the Event History Analysis per annum. The bars per year represent the number of articles. This limits the maximum impact per function per year and hence the article drop over the period 2001-2004 directly influences the results and should therefore be taken in consideration (see Appendix 11.9 for a large version of this graph)

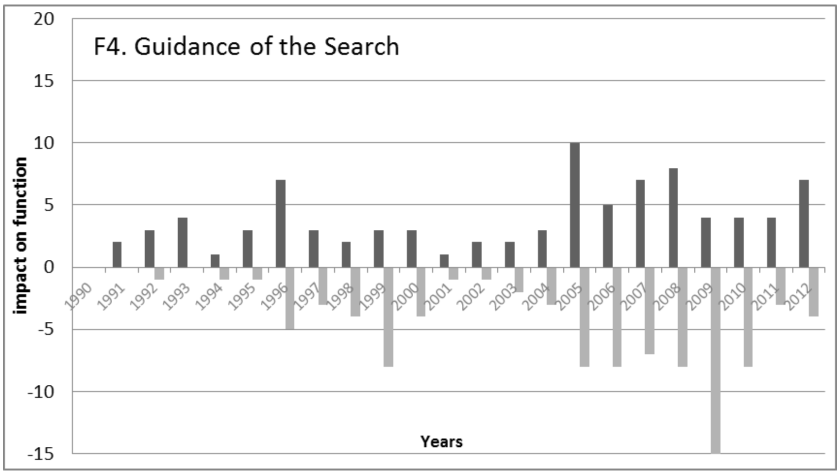


Figure 11: Graph on the functioning of Guidance of the Search (F4) as extracted from the Event History Analysis, in example measured by positive/negative expectations of the technology. The graphs of the all seven Functions are presented in Appendix 11.9.

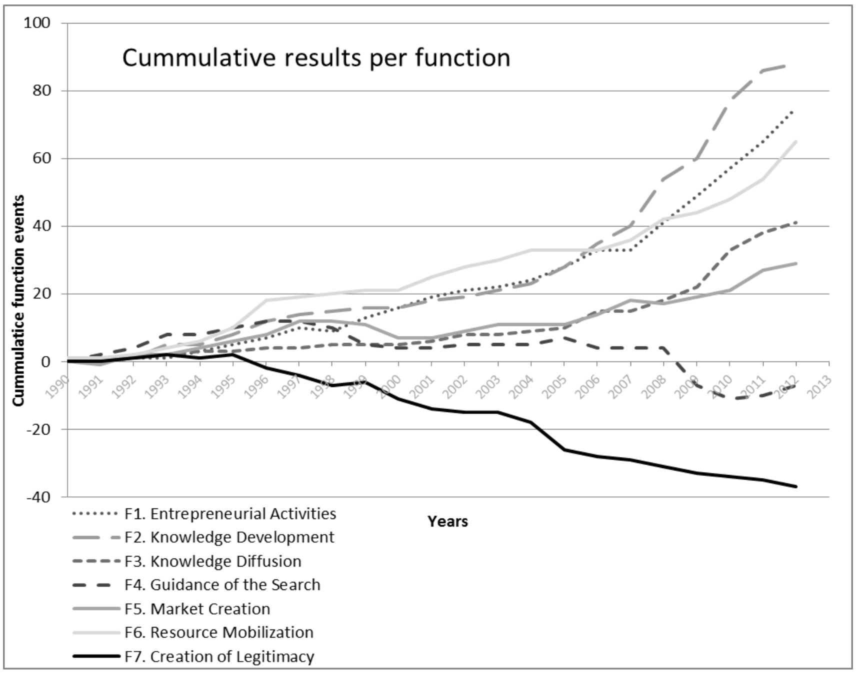


Figure 12: cumulative results of the Event History analysis per function representing the development per innovation system function over the years, starting in 1990. Especially function 7 and function 4 show to be developing negatively over the years. Both are important functions in the take-off phase and even in the acceleration phase both are still of importance (See Appendix 11.10 for a large version of this graph).

**F1. Entrepreneurial Activities** – Entrepreneurs have the important task to cope with the uncertainty related to innovation and consequently form an important factor in an innovation system (Hekkert et al., 2007). In the Netherlands the market for district heating is dominated by large energy corporations; i.e. Nuon Heat, Eneco, and Essent (see Figure 9). The Event History Analysis showed for Entrepreneurial Activities (see Figure 16 in Appendix 11.9) a rise of the projects started and initiated in the last decade. Therefore, F1 seems to be functioning properly according to what to expect from the phase of development of the technology. Nevertheless, for the enlargement of the DH sector new large projects are needed. The DH market is in need for new entries. Consumer collectives struggle to run a heating firm; for example Purmerend (Strategy Consultant, 6-2-2013). The incumbents are looking to write-off the DH systems connected to some power plants, as they can no longer guarantee full operation when the heat demand is present and the current contracts are expiring (Strategy Consultant, 6-2-2013). For some new parties it might be interesting to find new heat sources nearby and acquire these specific systems. New business cases are needed to develop such plans (Senior Bid manager, 6-2-2013). Currently, Essent and Nuon are retreating or planning to retreat from the heat sector, especially the smaller projects linked to written off electricity plants are sacked (Senior Bid manager, 6-2-2013). For large-scale energy infrastructures the whole system and all value chain actors are important and need to be aligned accordingly (Process Manager, 13-3-2013), because the projects are dependent on long-term upfront investments (CAPEX) (Process Manager, 13-3-2013). Technological developments in industrial sector are increasingly faster; the shorter cycles put pressure on residual heat delivery contracts (Senior Policy Advisor, 12-2-2013). It is difficult to acquire long-term contracts for small DH projects. For larger this can be overcome by the inclusion of multiple heat suppliers on one system, essentially creating a heat market (Strategy Consultant, 6-2-2013).

**F2. Knowledge Development (Learning)** – Without knowledge development and learning building an innovation system is not possible (Junginger et al., 2010). When looking at the knowledge basis for DH in the Netherlands this is largely vested in large energy corporations and a set number of project development contractors. In the Netherlands no specialist studies on vocational or university level are provided (Process Manager, 13-3-2013; Technical Specialist Heat, 25-2-2013). Some specialist courses are available, but the sector mostly relies on 'on-the-job' training (Technical Specialist Heat, 25-2-2013). When looking at the results from the Event History Analysis (Figure 17 in Appendix 11.9), the graph shows that there were numerous reports of studies and trails for DH, especially over the last decade. Consequently, it could be said that F2 seems to be functioning suitably according to what to expect in the development phase, however the technology is currently in the take-off phase and thus other functions are more important, such as Entrepreneurial Activities (F1) and Creating of Legitimacy (F7). The learning potential from for example Germany, Denmark, and Sweden is large (Independent Expert, 31-1-2013). For technological development there is potential in geothermal as a heat source for DH, however the underlying data necessary for the assessment of such for a specific area is not generally accessible (Strategy Consultant, 6-2-2013). Furthermore, there are gains in heat storage and the reduction of the transport heat loss (Senior Policy Advisor, 12-2-2013). The heat loss in transportation (20-30%) is an important improvement factor for DH, this currently constraints DH to local solutions (Senior Policy Advisor, 12-2-2013). Still, there is too little attention to schooling of engineers and technicians that can operate DH systems; this problem also arises with gas technology. Perhaps the technology is not interesting enough compared to electricity (Process Manager, 13-3-2013).

**F3. Knowledge Diffusion (Through Networks)** – To ensure that developed knowledge and information is used efficiently it needs to diffuse among the innovation system's actors. This enables the application and commercialization of the acquired knowledge. The diffusion of technological and business knowledge in the Netherlands is not open. The DH operating firms are not keen in sharing explicit knowledge on the business cases and technologies used. There is one specific network institute called Warmtenetwerk, which started in 2008. In this professional partnership professionals are brought together to talk about DH in general and even trips to foreign DH systems are organised. Nevertheless, the actual knowledge diffusion is not visible and no joint ventures are seen among the traditional DH firms. Perhaps Warmtenetwerk is operating more as a lobby club to place DH is positive light than as a knowledge network. There are trans-European knowledge projects, for example the SESAC demonstration project in which the municipality of Delft works together with the municipalities of Grenoble (France) and Växjö (Sweden). Learning from other European countries is sure to benefit the Dutch DH innovation system, because the Netherlands is far from a leading country in Europe. The Event History Analysis data reported of limited conferences, workshops, and alliances. The graph for this function (see Figure 18 in Appendix 11.9) is showing limited events over the period 1990-2005. In the last decade more events concerning the transfer of knowledge were visible in the data; however this is not the best performing function and lack of knowledge diffusion greatly hampers system development. Subsequently, F3 might form a limiting factor that requires attention when targeting to move from the Take-off into the Acceleration phase with the DH innovation system.

**F4. Guidance (of the Search)** – Expectations guide the direction of the search and are central at the moment of commercialisation of the technology and market growth. Reports on promises, expectations of the technology, and policy targets in line with the technology show to be ambivalent. This indicates a potential deficit in governmental regulations and negative expectations of the technology. The graph created form the Event History Analysis (see Figure 19 in Appendix 11.9) indicates and even distribution of positive and negative events, which inclines that the function in essence is not performing well. The consumer has clear demands, namely heat supply that is not more expensive than possible alternatives (Alliander, 2012). In general, DH should not be pushed if the general public's opinion is negative (Senior Policy Advisor, 12-2-2013).

**F5. Market Formation** – When market forces are not designed in favour of the technology, niches can be sought, which allow for the further refinement of both technology as the market form that is favourable to the technology. Market parties and the government are unclear how to progress with District Heating. Market actors indicate a lack of favourable tax regimes for DH and are against the roll out of the heat law. On the other hand, there are uncertainties on how environmental friendly District Heating actually is. In the Acceleration phase F5 is an important function and this provides direction for the identification of barriers to the development of the DH innovation system. When houses are needing less and less energy for heating, the demand of hot tap water is not sufficient anymore to be able to create a sound business case. There is a project paradox in this, as new projects are needed to further develop DH in the Netherlands, at some points the energy consumptions of housing surpasses viable DH business plans. At this point in time some Dutch municipalities are favourable to DH (Nieuwsbank, 2013). These are the places where the largest Dutch DH systems are found, such as Amsterdam, Utrecht, Rotterdam, and The Hague. For smaller cities the development of new systems hampers. Only when there is an existing DH system present with near to closing residual stream and nearby a new quarter is in planning, only then the development of a district heating system is potentially viable. In order to achieve sustainable goals it is important to bring actors together and work from out and energy starting point. How can the system energy wise optimized (Process Manager, 13-3-2013).

**F6. Resource Mobilization** – The availability of resources is crucial for innovation system growth and technological development. *"Resources, both financial and human capital, are necessary as a basic input to all activities within the innovation system"* (Hekkert et al., 2007, pp.425).The Netherlands is not known for stable subsidy schemes and in the current economic climate one would expect difficulties in finding funding for DH projects. However, in the last 15 years green funds have started to accumulate money and are keen to invest. The availability of residual heat streams and contracts between 'producing' and 'supplying' party form potential issues. See Figure 21 in Appendix 11.9 for the Event History analysis results. At the moment there is no direct finance difficulty, however creating viable business cases for DH is challenging (Senior Policy Advisor, 12-2-2013; Senior Bid manager, 25-2-2013; Policy Advisor, 5-3-2013). Especially when stable parties such as municipalities and grid companies are participating and backing the projects, the financing of a DH project is not directly a problem. Bringing together all the necessary parties in the value chain of the DH project is a challenge. In addition finding with current building sector issues, a housing project that is large enough for a DH system and nearby heat source is not self-evident. In Appendix 11.12 and 11.13 the heat potential of residual and geothermal sources are presented in the Netherlands. There appears to be sufficient heat available, nevertheless resources to create and build DH systems and funding to ascertain a viable business case is lacking (Senior Policy Advisor, 12-2-2013; Senior Bid manager, 25-2-2013; Policy Advisor, 5-3-2013). Due to the long-term investments needed for DH the calculation of viable business cases is difficult. Current parties try to overcome this by including up front connection costs, but these are not desirable as they impose a disadvantage compared to other technologies (Senior Policy Advisor, 12-2-2013).

**F7. Creation of Legitimacy/ Counteracting Resistance to Change** – The social acceptance of a technology influences the speed and direction in which resources are acquired and new projects developed. On the system level this can be achieved by stimulating other system function like guidance of the search (F4) or market formation (F5) (Hekkert et al., 2007), but also by convincing established actors or society of the technology´s benefits. According to the results from the Event History analysis this Function shows to be the least functioning factor (see Figure 22 in Appendix 11.9). The Dutch people are not undisputedly positive about the technology; nevertheless there are expectations of the positive environmental impact of DH compared to the use of gas condensing boilers. However, negative tendencies related to the billing schemes will hold back the willingness to use DH technology from a consumer's perspective. There is an expressed lack over government support that should have been captured by the heat law, however this law keeps being postponed for to the general public unclear reasons. Freedom of choice is a strong principle vested in Dutch collective memory (Integral Energy Consultant, 5-3-2013), this is something that plays a part when developing a district heating system in an existing neighbourhood. As happened in Amsterdam (Nieuwsbank, 2013), here consumers complained about the fact that they could not cook on gas anymore. For new neighbourhoods that problem is less visible as people then choose for that area to live in. (Strategy Consultant, 6-2-2013). Generally are consumers neutral against DH, as long as they do not feel that they pay more than others. Interviewees indicated that from a consumer's point of view it is perhaps a good idea to build in flexibility, freedom of choice (C. M. Christensen & Bower, 1996), and sense of ownership of the DH system. This can be operationalized by inclusion of representatives of the Association of Owners in a joint venture that operates the DH system (Senior Policy Advisor, 12-2-2013).

# 6. Analysis

In this chapter an analysis of the results of the two heat technology innovation systems is presented. This thesis has set out to identify barriers to the development of two innovation systems. The here provided analysis discusses the identified barriers with respect to the researched technological innovation systems. Conclusions are elaborated in Chapter 8. Further on, chapter 9 presents recommendations for further development of both TIS.

## 6.1 Innovation system development

Now that the description of the structural components and the system functions has been provided (see Chapter 4 & 5), attention can be given to the barriers to TIS development them against the systemic problem framework. Overall, the two systems have the potential to form a sustainable alternative for the supply of heat to households, compared to the current dominant design: the gas-condensing boiler. In addition, collective systems are generally speaking better performers on energy efficiency (Integral Energy Consultant, 5-3-2013). However, transparency among stakeholder is a premise for the success of such system (Independent Expert, 31-1-2013). Better connection and interaction between project developers, housing corporations, constructing firms, and infrastructural contractors are needed. Key is a total and overarching solution (Independent Expert, 31-1-2013). The transparency among stakeholders can be reached by for example the setup of joint venture structures; including also representatives from the homeowners and municipal government (Independent Expert, 31-1-2013). Individual leadership within municipal government tend to be a large advantage when a large infrastructural energy system is implemented (Patil et al., 2006; Policy Advisor, 5-3-2013; Project Manager, 14-2-2013). Leadership is crucial in the design and starting phase of both BioGrid as District Heating projects. The operational impact of the heat law are influences by the SER[8] agreements. Consequently, the upcoming agreement is impacting sustainable energy technologies from a regulatory perspective (Senior Bid manager, 6-2-2013), there are rumours of an additional sustainability fee of 6 eurocents per cubic meter of natural gas consumed. This will positively influence the relative advantage of both BioGrid as District Heating up against the Dutch dominant design, because both are compared to the capital and operational costs of this.

Furthermore, the government energy performance instrument the EPC leaves room for improvement. A flaw in the EPC instrument is the measurement of the actual achieved energy performance of the building (Independent Expert, 31-1-2013). This can be better institutionalised to ensure the building of environmentally friendlier housing. In the upcoming years the EPC norms will get stricter (see Table 1), demanding a better energy performance of housing resulting in lower heating demand. The exact scoring of both DH as BG in the EPC calculation are going to be crucial in the choice whether to further expand and develop these technologies (Independent Expert, 3-4-2013; Independent Expert, 31-1-2013; Integral Energy Consultant, 5-3-2013). In addition, especially for District Heating, the decrease of heat demand of homes is going to potentially form an issue

[8] Social and Economic Council of the Netherlands (SER)

(Technical Specialist Heat, 25-2-2013), because at some point the heat demand will become so low that for example a small electrical heater will be sufficient (Strategy Consultant, 6-2-2013). Of course will there always be a demand for hot tap water, but also solar boilers will impact the development (Integral Energy Consultant, 5-3-2013).

In essence, the EPC norm has set out to lower the energy consumption of homes, the positive environmental impact of using DH and BG instead of gas boilers has first proven to be a strong positive force (Independent Expert, 31-1-2013). Now, with the limited building of new neighbourhoods and increase of public awareness on insulation, as well as, a close watch by the ACM on DH projects there is limited interest by the current large players (i.e. NUON, Essent, and Eneco) to further roll out DH. The gap they leave creates opportunities for new entrants to the district heating market; such as, energy service companies, publicly initiatives from out Homeowner associations, or grid companies. These examples share that they are reliant on a different kind of consumer backing and have a different (often lower compared to commercial market parties) drive for return on investment. For the household consumer the ‘delivered good’ is a warm home. Research has indicated that the consumer does not favour a particular heating technology (Alliander, 2012), as long as there is certainty in delivery, low cost (compared to neighbours). However, further product and technological differentiation of both infrastructural energy systems is needed (Strategy Consultant, 6-2-2013; Product Developer, 6-2-2013; Manager R&D, 7-3-2013; Integral Energy Consultant, 5-3-2013). For the increase of the success of BG cooking can be an accelerating factor. This can be met by the development of a multi-gas stove, enabling consumers to cook in the gas distributed in the BioGrid. For District heating the accelerating factor lies at the supply side. With the further development of geothermal heat as a source for DH a new and sustainable energy source can be added to the system. There are currently various regulations and costs hampering the use of geothermal as a heat source. The test drilling is costly and time-consuming and permits are difficult to acquire (Independent Expert, 3-4-2013).

## 6.2 Barriers to TIS development

By use of the structural and functional TIS analysis and the systemic problem framework the barriers to the development of the BG and DH technological system are identified from the presented empirical data and results (Negro et al., 2012; Wieczorek & Hekkert, 2012). It must be noted that the barriers can change over time and are possibly not exhaustive perhaps other factors are present that remained outside the scope of this research, additional studies are to validate this. It is to the readers consent if the identified barriers actually form a barrier or a chance to step into the market by providing a remedy against it.

From the reviewed literature, the analysed interview data, Event History Analysis and social network analysis various barriers were identified. To provide some direction the typology of systemic problems is adapted (Wieczorek & Hekkert, 2012); to group the barriers and provide a better overview. In this research Technical issues are added to include the technological complexity of both technologies. The adopted systemic problem typology for this research consequently consists of five factors: Actor problems, i.e. poorly articulated demand, or capability failures; Institutional problems, i.e. unclear subsidies schemes or regulations favouring the current system; Network problems, i.e. lock-in failures or poor connectivity; Infrastructural problems (physical, knowledge, finance), i.e. mismatch between basic and applied research, investment issues; and Technology, compatibility with existing technology or better alternatives. At the moment the BioGrid system, under the premise that both the biogas source and heat demand is are present, is perhaps the most competitive compared to District Heating. However, current institutional alignment, consumer willingness, and local government voice are more in favour of District Heating. In the end, the energy system as a whole is to benefit from a move away from the current dominant heating design, especially when taking CO2-emissions into account. In that perspective a choice for either of the two is a choice for a more sustainable energy system.

Table 5 lists the barriers emerging from the analysed literature on infrastructural energy technologies in combination with the results from the methods adapted in the presented research. Some of the Barriers extracted from the data were not pointed out in literature, others were not directly forming a problem according to some of the interviewees. The position of the interviewee seems to greatly impact the angle and perspective on what is to be perceived as a barrier, ensuring representation of the multiple angles removes this potential bias. Barriers are even seen by some as potential niche markets (Manager R&D, 7-3-2013; Strategy Consultant, 6-2-2013). Removing the barriers will benefit the specific innovation system. Not one individual actor per se; as firm level innovation theories, such as the Resource Based View, would prescribe. A brief discussion of the technology specific innovation system development barriers is provided in section 6.2.1 and 6.2.2. Under the premise that removing the identified barriers will foster innovation system development, Chapter 9 presents recommendations on how to further develop both TIS.

Table 5: List of barriers to BioGrid and District Heating development presented per systemic problem typology. The barriers are present for the Netherlands and extracted from literature on infrastructural energy technologies, Event History Analysis of DH, interviews with experts and project data. The identified barriers are matched with the investigated technologies, BioGrid (BG) and District Heating (DH) respectively, the X indicates if the barrier is present for the specific innovation system. The corresponding sources are provided.

| **Barriers to BioGrid and District Heating innovation system development** | | | |
|---|---|---|---|
| **Actor** | **BG** | **DH** | **Source** |
| Risk aversion | X | X | Thollander et al. (2010); Patil et al. (2006); Process Manager (13-3-2013); Policy Advisor (5-3-2013) |
| Not core business | X | X | Ligtvoet (2012); Patil et al. (2006); Policy Advisor (5-3-2013) |
| Split drivers | X | X | Wüstenhagen & Boehnke (2008); Patil et al. (2006); Senior Policy Advisor (12-2-2013); Policy Advisor (5-3-2013) |
| Covering losses | | X | Strategy Consultant (6-2-2013); Manager R&D (7-3-2013) |
| Commitment end users | X | | Patil et al. (2006); Senior Policy Advisor (12-2-2013); Management Trainee (7-1-2013) |
| Alignment stakeholders | X | X | Patil et al. (2006); Strategy Consultant (6-2-2013); |
| Public opinion | X | X | Christensen & Bower (1996); Senior Policy Advisor (12-2-2013); Process Manager (13-3-2013); Independent Expert (3-4-2013) |
| **Institutional** | **BG** | **DH** | **Source** |
| Legal restrictions | X | | Ligtvoet (2012); Unruh (2002); Independent Expert (31-1-2013); Independent Expert (3-4-2013) |
| Long lead times and contracts | X | X | Wüstenhagen & Boehnke (2008); Grönkvist & Sandberg (2006); Strategy Consultant (6-2-2013) |
| Division of $CO_2$ permits | X | X | Ligtvoet (2012); Independent Expert (31-1-2013); Strategy Consultant (6-2-2013) |
| No clear incentive | | X | Senior Policy Advisor (12-2-2013); Independent Expert (31-1-2013) |

| ***Institutional*** | ***BG*** | ***DH*** | ***Source*** *(table 5 continued)* |
|---|---|---|---|
| EPC calculation | X | X | Independent Expert (3-4-2013); Integral Energy Consultant (5-3-2013); Process Manager (13-3-2013); Policy Advisor (21-1-2013) |
| Unclear laws and regulations | X | X | Patil et al. (2006); Unruh (2002); Strategy Consultant (6-2-2013); Independent Expert (31-1-2013) |
| **Network** | **BG** | **DH** | **Source** |
| Differences in views, values, drivers | X | X | Grönkvist & Sandberg (2006); Patil et al. (2006); Thollander et al. (2010); Ligtvoet (2012); Independent Expert (3-4-2013); Senior Bid manager (25-2-2013) |
| Trust and transparency | X | X | Grönkvist & Sandberg (2006); Patil et al. (2006); Thollander et al. (2010); Process Manager (13-3-2013) |
| Coordination of projects | X | | Ligtvoet (2012); Patil et al. (2006); Project Manager (14-2-2013); Process Manager (13-3-2013) |
| Division of risks | X | X | Patil et al. (2006); Senior Bid manager (6-2-2013); Strategy Consultant (6-2-2013); Integral Energy Consultant (5-3-2013) |
| **Infrastructural (physical, knowledge, finance)** | **BG** | **DH** | **Source** |
| Profitability business case | | X | Grönkvist & Sandberg (2006); Wüstenhagen & Boehnke (2008); Patil et al. (2006); Thollander et al. (2010); Process Manager (13-3-2013); Strategy Consultant (6-2-2013); Senior Bid manager (25-2-2013); Senior Bid manager (6-2-2013) |
| Long payback periods | X | X | Wüstenhagen & Boehnke (2008); Grönkvist & Sandberg (2006); Thollander et al. (2010); Process Manager (13-3-2013); Independent Expert (31-1-2013); Senior Bid manager (25-2-2013); Senior Bid manager (6-2-2013) |
| Low return on investment | | X | Wüstenhagen & Boehnke (2008); Grönkvist & Sandberg (2006); Thollander et al. (2010); Senior Bid manager (6-2-2013) |
| Split incentives | X | X | Grönkvist & Sandberg (2006); Wüstenhagen & Boehnke (2008); Thollander et al. (2010) |
| Biogas availability | X | | Senior Network Strategist (11-2-2013); Product Developer (6-2-2013); Consultant (12-3-2013); Integral Energy Consultant (5-3-2013) |
| Heat resource availability | | X | Integral Energy Consultant (5-3-2013); Independent Expert (3-4-2013) |
| Finding investor(s) | X | | Thollander et al. (2010); Wüstenhagen & Boehnke (2008); Grönkvist & Sandberg (2006); Senior Bid manager (25-2-2013); Senior Bid manager (6-2-2013); Senior Network Strategist (11-2-2013) |
| **Technical** | **BG** | **DH** | **Source** |
| Compatibility with current system | | X | Unruh (2000); Grönkvist & Sandberg (2006); Manager R&D (7-3-2013) |
| Competition with alternatives | X | X | Ligtvoet (2012); Grönkvist & Sandberg (2006); Independent Expert (31-1-2013) |
| Uncertainty technical data | X | X | Integral Energy Consultant (5-3-2013); Independent Expert (3-4-2013); Policy Advisor (21-1-2013) |

### 6.2.1 Barriers to BioGrid development

Here the barriers specific to the BioGrid innovation system are discussed. For the BG the majority of the barriers follow from the commercialization of the technology. This is largely dependent on new built neighbourhoods. The economic crisis also hits the building sector and the investment in new housing stagnated in the recent past. This is one of the reasons that until now the applicability of the BioGrid holds with the pilot projects currently managed by Alliander. Furthermore The Biogas availability and commitments of end users forms a barrier. Legal restrictions are indicated to be specifically of interest to BioGrid development. At the moment biogas en the BioGrid is not included in the Dutch gas law and parties are disagreeing how this should be operationalized. Furthermore finding investors and the coordination of projects is a barrier. A different skill set is desirable when engineering technology, than when entrepreneurial action is needed. Connecting and inclusion of the BioGrid value chain stakeholders will be essential. Looking at the next phase of development for the BioGrid innovation system: the Development phase. The key-factor for the move towards a next phase is entrepreneurial activities. Function 5 and 7 are less relevant as the interactions are still at individual level. The impact of the first domestic project will be large on the success of BioGrid as a commercial technology. The knowledge diffusion and demonstrating the technology in 'real life' situations at this point becomes more important than the development of new technical insights (Senior Network Strategist, 11-2-2013). As discussed earlier at the moment no commercial size BioGrid project exists yet. Commercial size would include at least a number of household consumers. In this perspective it can be beneficial to plan ahead and take up scaling as an option in the building process. Concrete this means implementing a building block system in which additional blocks can be added to the system when there are more resources at hand. This can also benefit the maintenance of particular parts of the system. One can than easily replace the part and maintain it in a specialized surrounding instead of having the ground open for long periods of time or the facility not operating for several days. Such block system will benefit the consumers directly as the security of supply is better ascertained and the producers are to benefit from the continued production and thus longer operating periods per annum, that impacts the realization of the calculated business case of the BioGrid.

### 6.2.2 Barriers to District Heating development

Here the barriers specific to the District heating innovation system are discussed. The low return on investment for DH projects impacts future business cases negatively and makes the covering of losses difficult. The current business cases are not living up to the prospects of further development. New types of business cases, incorporating all value chain actors should be able to form a concrete ground of furthering from out this issue. Furthermore, DH Projects are custom built, which adds to the investments costs of the project and lowers the potential return on investment. The advantage of custom building is the achievement of specific local energy efficiency, but perhaps standardization can help improve the roll out of more systems and perhaps a cost advantage. At the moment, large market parties look at reducing their DH portfolio. According to many there are no market related incentives on stimulating this technology. However, many municipalities struggle to reach their sustainability targets. When the division of $CO_2$ permits is improved these municipalities might become prime movers in the identification of new projects and return to potential market parties for help. Transparency among sectorial actors is needed in order to be able to supply to these prime movers. In addition the compatibility with the current system forms a barrier, because this limits the possibilities of further development to new building projects. The building sector is, due to the current financial climate, on a hold and thus finding new projects is difficult. Historically in the Netherlands DH systems were only most often linked to electricity plants. Over the next decade many of these plants are written off or not working at times heat demand is present. This puts pressure on heat source availability. The inclusion of industrial parties that have a surplus of heat and further research on geothermal is needed to overcome the barrier caused by heat source availability.

# 7. Discussion

This research has presented barriers to innovation system development specific for BioGrid and District Heating technology. It has coupled the structural and functional TIS analysis with the identification of the present phase of development and systemic problems perspective. From previous studies (i.a. van Alphen, 2011; Negro, 2007) proper methodologies were identified and assessed whether these would be helpful in answering the sub-questions and overarching research question. The results were presented systematically in order to allow for comparability of both technologies. In the analysis chapter the results of both technologies were coupled and abstracted to answer the research question. From the empirical data and the analysis this study identified barriers to BioGrid and District Heating innovation system development. However it is difficult to assess whether all possible barriers are included. Additional research, perhaps adopting a different theoretical or methodological perspective could clarify this. Nonetheless, the barriers identified from the literature review were underlined and validated by interviewees.

Methodological improvements are possible because some data sources are currently not available or not yet looked into. For example the network of both technologies is based on Project data. When acquiring a list of people that work actually on the projects a more deepened understanding of the knowledge streams and information diffusion can be achieved. A data source could be LinkedIn (a professional social network), from the linkages of identified actors a comprehensive analysis of interactions can be operationalized. At this point such study is because of various reasons not possible, amongst others privacy of the LinkedIn members. Another additional improvement is the formation of a multi-disciplinary research team takes up this topic. For example, if someone with a background in law would study the regulatory framework of the heat sector other suggestions might be formed then when assessed by someone with a technical education. In addition, when more people delve into the same topic, discussions on this topic might enhance the overview on the innovation system. On the other hand, communication issues may arise, as the complexity of the research will increase with every added researcher and each additional data source.

Earlier papers on the development of sustainable energy technologies (i.a. Unruh, 2000; Unruh, 2002; Foxon, 2007) identified a lock-in of the energy system, however did not move forward by identifying modes to move away from the identified lock-in. Wieczorek & Hekkert (2012) moved forward from the lock-in notion by arguing that the lock-in itself is created by underlying barriers. In that perspective this study added to the body of literature by providing insight in the barriers to BioGrid and District Heating development. Negro et al. (2012) studied why renewable energy technologies diffuse slowly, in that light the presented research fits to the findings of this research and adds to it by studying the system dynamics of two specific technologies. Alkemade & Suurs (2012) studied the importance of expectations of the technologies and concluded that this is important as well. However it is not the biggest issue at the moment. This legitimacy is impacted by the performance of the functions guidance of the search and market formation. The impact of other potentially competitive technologies did not belong to the scope of this research. A broader assessment of what technology will prevail to be the new Dutch dominant design from technology perspective can enlighten the view on future developments.

The systems perspective on technological development is a useful scope of analysis. However, when seeking to provide concrete advice for a specific set of actors other innovation theories might be more appropriate, i.e. the resource based view or dynamic capabilities perspective in combination with managerial implications in the form of specific routines. This study has focussed on the development of BioGrid and District heating in the Netherlands. The addition of an international research, including countries that take a lead in the technology might broaden the scope and the identification of ways forward. However, learning from technological progress in other cultures is not straight forward as underlined by various innovation scholars on path dependency. The availability of data suitable for a TIS analysis is always an issue, researchers have indicated this multiple times. Therefore, TIS studies generally strongly rely on interview data, with the impaired possibility of personal biases. The generation of generally accepted quantitative methods and leads on how to gather data might overcome this. This study has evaded possible biases by, apart from interviewing technology specific experts, interviewing experts that overview both technologies and do not favour one of the two. Furthermore, the preliminary results were triangulated by acquiring feedback from the interviewees. The number of interviews in this research was sufficient and at some point the number of barriers saturated. Nonetheless, one could wonder if the same results would be found if a different order of interviews would be held. However, the barriers identified in this research seem to be exhaustive as after approximately fifteen the interviews did not add anymore to the already identified barriers. Nevertheless, the remaining interviews did add to the structural and functional overview of both technologies and in particular the project data was further enhanced. Creating the project database was essential to the social network analysis. The knowledge is present with technology experts, but until this point, no one took the time to generate a project-based database of the technologies.

In due time, a new analysis of both innovation systems adopting similar methods could provide an overview on how to move even further in the development of the systems and how well the taken measures have functioned. Current ideas and assumptions might not be valid in the future. Further research on the link of the structural and functional analysis is needed and especially the link to suggestions to overcome system malfunctioning or limited system functioning needs to be worked on. The work of numerous researchers together could help to improve the search to this understanding. Even more important, thought is needed on whether the systems functions and even the structure of an innovation system are similar across sectors. Perhaps other functions are of influence in regard to energy technologies then with for example consumer electronics such as smart phones. The presented research overviews a substantial part of the innovation systems of both heating technologies and the identified barriers and presented suggestions to overcome such are strongly backed by empirical data. Experts agree that concrete steps are needed to further develop both systems to enhance the Dutch heating sector and strengthen sustainable heating technologies. The final chapter of this thesis, Chapter 9, presents an elaboration of suggestions for further development of the researched technological innovation systems.

# 8. Conclusion

The central theme of this research is the identification of barriers to BioGrid and District Heating development in the Netherlands. First an investigation of the phase of development of the technological systems is undertaken. This step leads to the understanding that the BioGrid system is in between the Pre-development and Development phase and the District Heating system is at the edge of the Take-off phase. The important functions for these phases are identified and have been used to further streamline the overall analysis. Subsequently, the structural and functional TIS analysis is performed and presented systematically. The analysis of these results has led to the identification of barriers that hamper the further development of both respective innovation systems (as presented in Table 5 on page 42). The presented barriers are the answer to the overall research question. The results for the phase of development and the innovation systems´ structure and functioning are the answers to the three sub/questions. This research argues that the application of the presented technologies will enhance the energy system's sustainability and by removing the identified barriers the TIS functioning will improve. Consequently, the removal of these barriers will increase the chance of reaching the Dutch environmental goals.

This thesis has attempted to present an overview of the barriers to the development of the BioGrid and District Heating innovation systems in the Netherlands. The adopted research methods are social network analysis, literature reviews, expert interviews, and event history analysis. These methods have proven to be suitable for the analysis of innovation system barriers. The empirical data associated with the presented methods was of various source types and sources. This ensured a broad perspective on the innovation systems' structures and functioning. The addition of a cumulative graph to the Event History Analysis demonstrated to be insightful for the analysis of system performance over time. Hereby a representation of the analysed data over time in for example a bar graph is needed to be able to interpret the lines in the cumulative graph. The available data for an event history analysis of the BioGrid system was because of the short existence of this system limited and not sufficient to perform this analysis for the BioGrid innovation system. This breach in empirical data was overcome by addition of interview data of potential biogas producers. This improved the analysis of the BioGrid innovation system as compared to the District Heating analysis. According to Wieczorek & Hekkert (2012), systemic problems and barriers to the development of technological innovation system can be overcome by applying specific systemic instruments. Consequently, most of the in this research identified barriers can be overcome (recommendations are provide in Chapter 9). Systemic instruments have been researched by several innovation scholars; i.e. Chaminade & Edquist (2010) and Jacobsson & Johnson (2000). Nevertheless, systemic problems and systemic instruments are poorly linked; this leaves room for additional empirical research.

After analysing the innovation systems of BioGrid and District Heating in the Netherlands it can be concluded that there are multiple barriers to the innovation system development. The from empirical data extracted barriers can perhaps be further substantiated by the addition of other research methods; this is discussed in Chapter 7. The analysis showed that for both TIS the fact that new housing market is stagnating forms a barrier. Finding a location for a new District Heating project and the first BioGrid project is going to be crucial for the further development of both TIS. Particularly for BioGrid a first commercial application needs to be realised to show a large scale proof of concept. To BioGrid and District Heating development prominent barriers are the lack of new projects and the difficulty of creating viable business cases. These barriers are mainly caused by long payback periods and low return on investments. Another prominent barrier is the availability of the heat source or biogas and consequent coupling of heat demand. The identification of potential sources and demand will be crucial and currently the available data is not fine-grained enough. Matching both supply and demand will be an important and most of the costs of the projects lie within the infrastructure. For both infrastructural technologies the alignment of stakeholders is crucial, because the business case of the project is built on long-term investments that include the associated risk. Alliances will strengthen the innovation system by better knowledge diffusion, easier resource mobilization, and a stronger market formation. For example by increasing interaction with the systems actors; i.e. government and knowledge institutes (Caniëls & Van den Bosch, 2011). A proactive inclusion of the government, both national as local, will create a sense of urgency for the further development of the technologies and search for new projects. This will impact the development of both innovation systems positively.

Overall, the granted energy performance coefficient (EPC) of both sustainable heating technologies will greatly influence the development of the TIS. The EPC is a Dutch policy instrument applied in search for lower $CO_2$-emissions in the built environment. Furthermore, the sustainability of both systems is not generally agreed up on. The environmental friendliness this is not (yet) formalised in standards and regulations (NEN, 2011; van Wolferen et al., 2013). Consequently, the EPC calculations for both technologies are claimed to be close to zero, but this cannot be underlined by regulations. For example, for the production of biogas it is questionable how sustainable the biomass resources are, because it is difficult to know what actually is used in the digester. For District Heating the EPC also depends on the heat source. If an additional backup unit is needed a higher EPC is calculated. This means that for future projects both a sustainable heat source as a demand control system are needed. The demand control system ensures that the total heat demand of the system at all times does not go beyond the heat source capacity. In 2020 the required EPC is likely going to be 0 and subsequently the EPC of both systems will need to be zero in order to remain a sustainable heat option when stricter EPC norms are implemented. In the District Heating innovation system some actors have strong vested interests and not likely to move away from their position. However, because of international takeovers, some of the traditional District Heating systems operators have looser connection with the geographical areas where the heating systems are operated. Parties with stronger regional bounding are likely to take over. If the above barriers can be overcome than the further development of both heating technologies will be prosperous, especially compared to the current Dutch dominant design.

# 9. Recommendations for further development

While uncertainty could provide reason to delay action, the presented results for both innovation systems and identification of barriers to TIS development has reduced much of this uncertainty. This Chapter sets out to provide directional recommendations for further development of both innovation systems, under the premise that both are beneficial to the Dutch energy system and therefore should be further developed. The recommendations are written from the perspective of grid company Alliander.

Literature on systemic instruments provides insight in how to overcome systemic problems and in consequence the underlying (and in this research identified) barriers to the development of the BioGrid and District Heating innovation systems. However, the literature on systemic instruments is poorly linked to the literature on systemic problems (Wieczorek & Hekkert, 2012). Therefore, it is not yet theoretically validated what kind of measures to take against specific barriers, and even more important, a seemingly similar barrier can need a different approach when present in a different technological innovation system. Therefore the below presented recommendations are to be taken as a direction for further development and not as a recipe for the improvement of the innovation systems of BioGrid and District Heating. The recommendations are not directed in a particular direction however assume Alliander to be an actor within the respective innovation system, in addition it is assumed that the Alliander actually has the power to perform the suggested action(s). Building on the typology of systemic problems presented in section 1.2 the systemic instruments will cover the same set of factors: Actors, Networks, Institutions, Infrastructure, and Technology. The advice is directed towards these and linked to the underlying barriers as presented in Chapter 6.

Moving forward and keeping the barriers presented in Table 5 in mind potential beneficial Systemic instruments are (adapted from Wieczorek & Hekkert, 2012): Build and organise innovation systems; Provide a platform for learning and experimenting; Provide an infrastructure for strategic intelligence and stimulate demand articulation; Manage interfaces; Develop strategy and vision. Below these are linked to more concrete actions. The listed actions are based on the tools described by (Wieczorek & Hekkert, 2012) and filtered for applicability for the BG and DH innovation system. Overall it is important to understand what is going on in the sector and to remain ahead of the general business. Hughes (1987) already pointed to this by identifying the necessity of a ‘prime mover’ or ‘system builder’, an actor (or set of actors) who are so financially and/or politically powerful that they can strongly influence the development and diffusion process. Below directional suggestions are provided and elaborated briefly; these are linked to the adopted systemic problems typology: actors, network, institutions, infrastructure, and technology (Wieczorek & Hekkert, 2012).

**Stimulate and organise participation of actors** – As discussed in Chapter 6 is the inclusion and alignment of value chain stakeholders important and currently and point of concern. One can look at the overall innovation systems and look for the *formation of clusters*. In the DH innovation system these clusters are already created. It is important to become part of such, perhaps through *new* *forms of Public Private Partnerships*. Furthermore can actively seek for the involvement of stakeholders in *public debates*, *thematic meetings* and *workshops*. Furthermore, the inclusion of knowledgeable venture capital and risk capital will help to further develop the sector, as the shared knowledge with these financial partners will likely end up by sectorial ‘partners’.

**Create space for actors’ capability development** – this is linked closely to the formation of dynamic capabilities. *Education and training programmes, technology platforms, pilot and demonstration projects, and scenario development* will increase the likelihood of the creation of dynamic capabilities. The formation of a transferable skill set will further improve the learning by doing (on the job training). Other techniques include: back casting, foresights, road mapping, and brainstorming. The creation of space for the development of the capabilities of the innovation systems’ actors ensures that the TIS will be able to learn and further improve on technologies.

**Stimulate occurrences of interactions** – this is important to allow for technology transfer. Mechanisms include: *cooperative research programmes, development conferences, cooperative grants, collaboration schemes*. This further stimulates the evaluation of public policy and lastly facilitating debates for decision-making will ensure that from the enabled interactions leadership and action occurs.

**Prevent too strong and too weak ties** – It is important that innovation system networks are linked but not to clustered as this will induce the prevention of knowledge spill overs. Actors are keen on sharing knowledge with parties that are not likely to strive over the same market share. Timely *procurement* (strategic, public, R&D-friendly), *demonstration centres, strategic niche management,* and *technology promotion programmes* are mechanisms to allow for interactions but are at enough distance to still be of benefit.

**Secure presence of (hard and soft) institutions** – As previously mentioned in the thesis it is important to include municipal governments early in the potential project. These are at an early stage possible lead. Key here are *awareness building measures* and information and *education campaigns*, for example demonstration projects, thereby a broader public is included en potential enthusiasts can become ambassadors of the technology. Other actions beneficial to this systemic instrument are the origination of *public debates*, *lobbying*, and *voluntary agreements*.

**Stimulate physical, financial and knowledge infrastructure** – Without financial resources are large infrastructural projects not possible. It can be beneficial to at a preliminary phase already include *funds, subsidies,* or *include public research*. This will direct the formation of business cases. Nevertheless be aware that this sometimes imposes directions not necessarily favourable on the long run. These infrastructures should be utilised strategically.

# 10. References

Agentschap NL. (2010). Warmte in Nederland - Onze warmtebehoefte kost veel energie: grote besparingen zijn mogelijk No. 2NECW1003). Utrecht: Agentschap NL.

Alkemade, F. & R.A.A. Suurs. (2012), Patterns of expectations for emerging sustainable technologies. Technological Forecasting and Social Change 79(3), pp.448-456.

Alliander. (2012). Wie verwarmt de toekomst? Inventarisatie en beoordeling van kansrijke technologiën om huizen te verwarmen in een aardgasloze toekomst.

Alliander. (2013). Liander opent demonstratieproject BioNet [online]. Retrieved May 30, 2013. Available on the world wide web: <http://www.liander.nl/liander/over_liander/2013/liander_opent_demonstratieproject_bionet.htm>.

Alphen, K.v. (2011). Accelerating the development and deployment of carbon capture and storage technologies: an innovation system perspective. Unpublished PhD, Utrecht University.

Arthur, W.B. (1989), Competing technologies, increasing returns, and lock-in by historical events. The economic journal 99(394), pp.116-131.

Bastian, M., S. Heymann & M. Jacomy. (2009). Gephi: An open source software for exploring and manipulating networks. Proceedings of the Third International ICWSM Conference,

Bergek, A., M. Hekkert & S. Jacobsson. (2008a). Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers. In T. Foxon, J. Köhler & C. Oughton (Eds.), Innovation for a low carbon economy: economic, institutional and management approachespp. 79-112Edward Elgar Pub.

Bergek, A., S. Jacobsson, B. Carlsson et al. (2008b), Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy 37(3), pp.407-429.

Bouwbesluit. (2011). Besluit van 29 augustus 2011 houdende vaststelling van voorschriften met betrekking tot het bouwen, gebruiken en slopen van bouwwerken (Bouwbesluit 2012) (Staatsblad van het Koninkrijk der Nederlanden

Caniëls, M.C. & H. Van den Bosch. (2011), The role of Higher Education Institutions in building regional innovation systems. Papers in Regional Science 90(2), pp.271-286.

CBS. (2013). Industrie en Energie - Cijfers [online]. Retrieved January 8, 2013. Available on the world wide web: <http://www.cbs.nl/nl-NL/menu/themas/industrie-energie/cijfers/default.htm>.

Chandy, R.K. & G.J. Tellis. (2000), The Incumbent's Curse? Incumbency, Size, and Radical Product Innovation. Journal of Marketing 64, pp.1-17.

Christensen, C.M., H. Baumann, R. Ruggles et al. (2006), Disruptive innovation for social change. Harvard business review 84(12), pp.94-101+163.

Christensen, C.M. & J.L. Bower. (1996), Customer power, strategic investment, and the failure of leading firms. Strategic Management Journal 17(3), pp.197-218.

Christensen, C.M., M.W. Johnson & D.K. Rigby. (2002), Foundations for growth: How to identify and build disruptive new businesses. MIT Sloan Management Review 43(3), pp.22-31.

Christensen, C.M. & R.S. Rosenbloom. (1995), Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network. Research Policy 24(2), pp.233-257.

David, P.A. (1985), Clio and the Economics of QWERTY. The American Economic Review 75(2), pp.332-337.

ECF. (2010). Roadmap 2050 - A practical guide to a prosperous low-carbon Europe - Technical analysis No. Volume 1)European Climate Foundation (ECF).

Edquist, C. (2005). Systems of innovation. Technologies, Institutions, and OrganizationsRoutledge.

Foxon T., R. Gross, P. Heptonstall et al. (2007). Energy Technology Innovation: A Systems PerspectiveGarnaut Climate Change Review.

Freeman, R. E. (1984). Strategic Management: A stakeholder approach. Boston: Pitman.

Gemeente Amsterdam. (2009). Stadsverwarming [online]. Retrieved December 21, 2012. Available on the world wide web: <http://www.amsterdam.nl/gemeente/organisatie-diensten/dmb/doet-dmb/wat/advies-beleid/milieuadvies/projecten/luchtkwaliteit/actieplan/overzicht-acties/acties/stadsverwarming/>.

Hardi, E. (2011). Biogrid - biogas supply through a special distribution grid and adjustment of residential appliances. International Gas Research Conference, Seoul,

Hekkert M. P., S. de Boer & C. Eveleens. (2011). Innovatiesysteemanalyse voor beleidsanalisten - Een handleiding. Utrecht: Universiteit Utrecht.

Hekkert, M.P., R. Harmsen & A. de Jong. (2007), Explaining the rapid diffusion of Dutch cogeneration by innovation system functioning. Energy Policy 35(9), pp.4677-4687.

Hekkert, M.P. & S.O. Negro. (2009), Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technological Forecasting and Social Change 76(4), pp.584-594.

Hekkert, M.P., R.A.A. Suurs, S.O. Negro et al. (2007), Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change 74(4), pp.413-432.

Hillman, K.M., R.A.A. Suurs, M.P. Hekkert et al. (2008), Cumulative causation in biofuels development: A critical comparison of the Netherlands and Sweden. Technology Analysis and Strategic Management 20(5), pp.593-612.

Hughes, T.P. (1987). The evolution of large technological systems. The social construction of technological systems: New directions in the sociology and history of technologypp. 51-82

IEA. (2008). CHP/DHC Country Scorecard: The Netherlands. Paris: The INternational CHP/DHC Collaborative.

IEA. (2011). Energy-efficient Buildings: Heating and Cooling Equipment (Technology Roadmap

Jacobsson, S. & A. Johnson. (2000), The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy 28(9), pp.625-640.

Junginger, M., W. van Sark & A. Faaij, eds. (2010), Technological Learning in the Energy Sector - Lessons for policy, industry and scienceEdward Elgar.

Kamp L. M., S.O. Negro, V. Vasseur et al. (2009). The Functioning of Photovoltaic Techniological Innovation Systems - A comparison between Japan and the Netherlands. Copenhagen: Druid summer conference.

Latta, P. & E. Hardi. (2009), Biogas injection in the local natural gas grid – issues and solutions, monitoring and control in pilot case.

LexisNexis. (2012). LexisNexis Nederland [online].Available on the world wide web: <http://www.lexisnexis.nl/dutch/>.

Lintsen, H. (2005). Made in Holland - Een techniekgeschiedenis van Nederland [1800-2000]Walburg Pres.

Markard, J. & B. Truffer. (2008), Technological innovation systems and the multi-level perspective: Towards an integrated framework. Research Policy 37(4), pp.596-615.

Ministerie EL&I. (2011). Energierapport 2011. Den Haag: Ministerie van Economische Zaken, Landbouw & Innovatie.

Musiolik, J., J. Markard & M. Hekkert. (2012), Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. Technological Forecasting and Social Change 79(6), pp.1032-1048.

Negro, S.O. (2007). Dynamics of Technological Innovation Systems - The Case of Biomass Energy. (PhD, Utrecht University), Netherlands Geographical Studies, 356 (ISBN 90-978-90-6809-397-1)

Negro, S.O., M.P. Hekkert & R.E.H.M. Smits. (2007), Explaining the failure of the Dutch innovation system for biomass digestion—A functional analysis. Energy Policy 35, pp.925-938.

Negro, S.O., F. Alkemade & M.P. Hekkert. (2012), Why does renewable energy diffuse so slowly? A review of innovation system problems. Renewable and Sustainable Energy Reviews 16(6), pp.3836-3846.

NEN. (2011). Waardering biomassa in EPC (NEN 5128 en NEN 2916) NEN 7120 en energielabels (Memo No. 2011-047)Nederlands Normalisatie-instituut.

NEN. (2012). EPG per 1 juli 2012 van start [online]. Retrieved December 7, 2012. Available on the world wide web: <http://www.nen.nl/web/Normshop/EPG-per-1-juli-2012-van-start.htm>.

Nieuwsbank. (2013). Gemeente Amsterdam en Nuon bundelen krachten voor duurzame stad [online]. Retrieved May 29, 2013. Available on the world wide web: <http://www.nieuwsbank.nl/inp/2013/05/29/Y045.htm>.

Pinch, T.J. & W.E. Bijker. (1984), The social construction of facts and artefacts: or how the sociology of science and the sociology of technology might benefit each other. Social Studies of Science, pp.399-441.

Pront-van Bommel S. (2012). Energie-efficiëntie en gebiedsontwikkeling No. BR 2012/153)

Rijksoverheid. (2012). Wat is de energieprestatiecoëfficiënt?[online]. Retrieved October 20, 2012. Available on the world wide web: <http://www.rijksoverheid.nl/onderwerpen/energiebesparing/vraag-en-antwoord/wat-is-de-energieprestatiecoefficient-epc.html>.

Rogers, E. M. (2003). Diffusions of Innovations (Fifth ed.). New York: Simon & Schuster.

Stockroos, M. (2001). Verwarmen en verlichten in de negentiende eeuwWalburg Pers.

Suurs, R.A.A. (2009). Motors of Sustainable Innovation - Towards a theory on the dynamics of technological innovation systems. (PhD, Utrecht University)), (ISBN 978-90-6266-264-7)

Suurs, R.A.A. & M.P. Hekkert. (2009), Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. Energy 34(5), pp.669-679.

Suurs, R.A.A., M.P. Hekkert, S. Kieboom et al. (2010), Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel. Energy Policy 38(1), pp.419-431.

Suurs, R.A.A., M.P. Hekkert & R.E.H.M. Smits. (2009), Understanding the build-up of a technological innovation system around hydrogen and fuel cell technologies. International Journal of Hydrogen Energy 34(24), pp.9639-9654.

Suurs, R.A.A. & M.P. Hekkert. (2009), Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands. Technological Forecasting and Social Change 76(8), pp.1003-1020.

Technisch Weekblad. (2013, 28 May). Biogas kan direct naar cv-ketel in BioNet. Technisch Weekblad, T. van de Sandt

Tushman, M.L. & P. Anderson. (1986), Technological discontinuities and organizational environments. Administrative science quarterly, pp.439-465.

Unruh, G.C. (2000), Understanding carbon lock-in. Energy Policy 28(12), pp.817-830.

Unruh, G.C. (2002), Escaping carbon lock-in. Energy Policy 30(4), pp.317-325.

van Alphen, K., M.P. Hekkert & W.C. Turkenburg. (2010), Accelerating the deployment of carbon capture and storage technologies by strengthening the innovation system. International Journal of Greenhouse Gas Control 4(2), pp.396-409.

van Alphen, K., P.M. Noothout, M.P. Hekkert et al. (2010), Evaluating the development of carbon capture and storage technologies in the United States. Renewable and Sustainable Energy Reviews 14(3), pp.971-986.

van Wolferen H., R. van der Aa & A. van der Horn. (2013). Waardering biobrandstoffen in EPCNEN.

WarmteAtlas.nl. (2013). WarmteAtlas Nederland - Het project WarmteAtlas wordt uitgevoerd in opdracht van het ministerie van economische zaken.[online]. Retrieved April 11, 2013. Available on the world wide web: <www.WarmteAtlas.nl>.

Wasserman, S. & Faust, K. (1994). Social network analysis: Methods and applications (Vol. 8 ed.)Cambridge university press.

Wieczorek, A.J. & M.P. Hekkert. (2012), Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy 39(1), pp.74-87.

# 11. Appendix

## 11.1 Interview questions for the semi-structures interview

Table 6: Indicative questions that reflect the extent to which each function in the innovation system is fulfilled by the components of the system (adapted from van Alphen, 2011). These questions are utilized for semi-structured interviews with experts from both innovation systems.

| |
|---|
| **F1. Entrepreneurial Activities** |
| The number and the degree of variety in entrepreneurial experimentations?<br>The number of different types of applications?<br>The breadth of technologies used and the character of the complementary technologies employed?<br>The number of new entrants and diversifying established firms? |
| **F2. Knowledge Creation** |
| The number and degree of variety in RD&D projects?<br>The type of knowledge (scientific, applied, patents) that is created and by whom?<br>The competitive edge of the knowledge base?<br>The (mis-) match between the supply of technical knowledge by universities and demand by industry? |
| **F3. Knowledge Diffusion** |
| The amount and type of (inter) national collaborating between actors in the Innovation System?<br>The kind of knowledge that is shared within these existing partnerships?<br>The amount, type and 'weight' of official gatherings (e.g. conferences, platforms) organized?<br>Configuration of actor-networks (homo, or heterogeneous set of actors)? |
| **F4. Guidance** |
| Amount and type of visions and expectations about the technology?<br>Belief in growth potential?<br>Clarity about the demands of leading users?<br>Specific targets or regulations set by the government or industry? |
| **F5. Market Formation** |
| What phase is the market in and what is its (domestic & export) potential?<br>Who are the users of the technology how is their demand articulated?<br>Institutional stimuli for market formation?<br>Uncertainties faced by potential project developers? |
| **F6. Resource Mobilization** |
| Availability of human capital (through education, entrepreneurship or management)?<br>Availability of financial capital (seed and venture capital, government funds for RD&D)?<br>Availability of complementary assets (complementary products, services, network infrastructure)?<br>Level of satisfaction with the amount of resources? |
| **F7. Creation of Legitimacy** |
| Public opinion towards the technology and how is the technology depicted in the media?<br>What are the main arguments of actors pro or against the deployment the technology?<br>Legitimacy to make investments in the technology?<br>Activity of lobby groups active in the Innovation System (size and strength)? |

## 11.2 List of interviewees

Table 7: The list of the 22 conducted interviews with experts, discussing the innovation system of the respective technology related to their expertise or both, if applicable. Digital recordings can be provided after contacting the thesis researcher, contact info can be found on the title page.

| Technology | Job title | Interview date |
|---|---|---|
| Both | Process Manager | 13-mrt |
| Both | Integral Energy Consultant | 5-mrt |
| Both | Policy Advisor | 4-apr |
| Both | Independent Expert | 31-jan |
| Both | Independent Expert | 3-apr |
| District Heat | Policy Advisor | 5-mrt |
| District Heat | Senior Bid manager/ Key account manager | 25-feb |
| District Heat | Strategy Consultant | 6-feb |
| District Heat | Senior Bid manager | 6-feb |
| District Heat | Manager/Technical Specialist Heat | 25-feb |
| District Heat | Senior Policy Advisor | 12-feb |
| District Heat | Project and Process Manager | 8-apr |
| District Heat | Project Manager | 11-feb |
| BioGrid | Project Manager | 14-feb |
| BioGrid | Strategy Consultant/ Innovation Manager | 14-mrt |
| BioGrid | Product Developer | 6-feb |
| BioGrid | Manager R&D | 7-mrt |
| BioGrid | Management Trainee | 7-jan |
| BioGrid | Senior Network Strategist | 11-feb |
| BioGrid | Gas Consultant | 19-feb |
| BioGrid | Technical Trainee | 18-mrt |
| BioGrid | Consultant | 12-mrt |

## 11.3 List of BioGrid actors

Table 8: Table of the BioGrid actors and their occurrence in the investigated projects, alphabetically.

| BioGrid Actor | # |
|---|---|
| Alliander | 5 |
| ATAG Verwarming | 3 |
| Avri | 1 |
| Duurzame Energie Consult B.V. | 1 |
| Gemeente Amsterdam | 1 |
| Gemeente Dronten | 1 |
| Gemeente Eerbeek | 1 |
| Gemeente Neerijnen | 1 |
| Industriewater Eerbeek | 1 |
| Kiwa | 1 |
| LowCoNox | 1 |
| Ministerie BZK | 1 |
| Ministerie EZ | 1 |
| OOST | 1 |
| RWZI Dronten | 1 |
| Stichting BioMassa Hellouw | 1 |
| TNO | 1 |
| Van der Wiel Holding | 1 |
| Waternet | 1 |
| Woningbouwcorporatie | 1 |

## 11.4 Dutch BioGrid projects and their corresponding actors

Table 9: List of the Dutch BioGrid projects and the corresponding actors utilised for the social network analysis.

| Project 'name' | Actors |
|---|---|
| Concept ontwikkeling | Alliander; ATAG Verwarming; LowCoNox; OOST; TNO; Kiwa; Duurzame Energie Consult B.V. |
| Neerijnen | Gemeente Neerijnen; Alliander; Avri; ATAG Verwarming; Stichting BioMassa Hellouw; Ministerie EZ |
| Eerbeek | Alliander; ATAG Verwarming; Gemeente Eerbeek; Industriewater Eerbeek |
| Dronten | Dronten; gemeente Dronten; Alliander; RWZI Dronten; Van der Wiel Holding |
| Amsterdam | Alliander; Waternet; Gemeente Amsterdam; Woningbouwcorporatie; Ministerie BZK |

## 11.5 List of District Heating actors

Table 10: Table of the District Heating actors and their occurrence in the investigated projects, alphabetically (Gem. Is the abbreviation of Gemeente; Dutch for Municipality).

| District Heating actor | # | District Heating actor | # |
|---|---|---|---|
| A. Hak | 3 | Gem. Goes | 1 |
| AEB | 1 | Gem. Heerhugowaard | 1 |
| Alliander | 1 | Gem. Heerlen | 1 |
| ARN | 1 | Gem. Helmond | 1 |
| AVR | 1 | Gem. Hilversum | 1 |
| AVR Afvalverwerking | 1 | Gem. Hoek van Holland | 1 |
| BAM | 3 | Gem. Houten | 1 |
| BES | 1 | Gem. Leeuwarden | 1 |
| Cobas B.V. | 1 | Gem. Leiden | 1 |
| Cogas B.V. | 1 | Gem. Lelystad | 1 |
| Cogas Duurzaam | 2 | Gem. Made | 1 |
| DEVO | 1 | Gem. Nijmegen | 3 |
| E. On | 3 | Gem. Papendrecht | 1 |
| Electrabel | 1 | Gem. Purmerend | 1 |
| ELES | 12 | Gem. Rotterdam | 3 |
| Eneco | 10 | Gem. Sittard | 1 |
| Eneco DEP | 8 | Gem. Tilburg | 1 |
| Eneco Warmte | 5 | Gem. Utrecht | 3 |
| Essent | 13 | Gem. Velp | 1 |
| Essent Energy Trading | 3 | Gem. Wageningen | 1 |
| Essent Warmte | 14 | Gem. Waspik | 1 |
| Gem. Alkmaar | 2 | Gem. Westervoort | 1 |
| Gem. Almelo | 2 | Gem. Zandvoort | 1 |
| Gem. Almere | 1 | Gem. Zeewolde | 1 |
| Gem. Amersfoort | 1 | Gem. Zoetermeer | 1 |
| Gem. Amstelveen | 1 | Heijmans | 9 |
| Gem. Amsterdam | 3 | HVC | 1 |
| Gem. Apeldoorn | 1 | Indigo | 1 |
| Gem. Arnhem | 1 | MeerWarmte | 1 |
| Gem. Assendelft | 1 | Nacap | 8 |
| Gem. Barendrecht | 1 | Nuon Business | 5 |
| Gem. Bergen op Zoom | 1 | Nuon ET&W | 6 |
| Gem. Bergeschenkbroek | 1 | Nuon Renewables | 1 |
| Gem. Breda | 1 | Nuon Warmte | 30 |
| Gem. Broek op Langendijk | 1 | Nuon WKC Kleefsewaard | 1 |
| Gem. Culemborg | 1 | Provincie Gelderland | 1 |
| Gem. Den Haag | 3 | RWZI | 1 |
| Gem. Deventer | 2 | Stadsverwarming Purmerend | 1 |
| Gem. Duiven | 1 | VSH | 6 |
| Gem. Ede | 1 | Wamob | 1 |
| Gem. Eindhoven | 1 | Warmtebedrijf Rotterdam | 1 |
| Gem. Enschede | 2 | Westpoort Warmte | 1 |
| Gem. Geertruidenberg | 1 | | |

## 11.6 Dutch District Heating projects and their corresponding actors

Table 11 Table of the Dutch DH projects and the corresponding actors.

| Project 'name' | Actors |
|---|---|
| Almere | Gem. Almere; Nuon Warmte; Electrabel; Nacap |
| Amernet | Gem. Tilburg; Gem. Breda; Gem. Made; Gem. Waspik; Gem. Geertruidenberg; Essent Warmte; Essent Energy Trading; BAM |
| Amstelveen | Gem. Amstelveen; Eneco; Nuon ET&W; VSH |
| Arnhem | Gem. Arnhem; Nuon Warmte; Nuon WKC Kleefsewaard; VSH |
| Assendelft | Gem. Assendelft; Nuon Warmte; Nuon Business |
| Boekelermeer | Gem. Alkmaar; MeerWarmte; HVC; Nacap |
| Boterdorp | Gem. Bergeschenkbroek; Eneco; Eneco DEP |
| Botlekstraat | Gem. Deventer; Essent; Essent Warmte; Heijmans; ELES |
| Broek op Langendijk | Gem. Broek op Langendijk; Nuon Warmte; Nuon Business |
| Camminghaburen | Gem. Leeuwarden; Essent; Essent Warmte; ELES |
| Den Haag | Gem. Den Haag; Eneco; E. On |
| DGO | Gem. Nijmegen; ARN; Alliander; Provincie Gelderland; Nuon; Indigo; A. Hak |
| DNWW | Gem. Rotterdam; AVR; Nuon; Eneco; Warmtebedrijf Rotterdam; VSH |
| Duiven/Westervoort | Gem. Duiven; Gem. Westervoort; AVR Afvalverwerking; Nuon Warmte |
| Enschede | Gem. Enschede; Essent Warmte; Essent Energy Trading |
| Heerhugowaard | Gem. Heerhugowaard; Nuon Warmte; Nuon Business; Nacap |
| Het Loon | Gem. Heerlen; Essent; Essent Warmte; Heijmans; ELES |
| Hilversum | Gem. Hilversum; Nuon Warmte; Nuon Warmte |
| Hoogveld | Gem. Sittard; Essent; BES; Essent Warmte; BAM; ELES |
| Hoogvliet | Gem. Rotterdam; Nuon Warmte; Nuon Warmte; Nacap; VSH |
| Kernhem | Gem. Ede; Nuon Warmte; Nuon Warmte; Nacap |
| Leiden | Gem. Leiden; Nuon Warmte; E. On |
| Lelystad | Gem. Lelystad; Nuon Warmte; Nuon Renewables; Nuon Warmte |
| Marienburg | Gem. Nijmegen; Nuon Warmte; Nuon Warmte |
| Meerhoven | Gem. Eindhoven; Essent; Essent Warmte; Heijmans; ELES |
| Oosterheem | Gem. Zoetermeer; Eneco; Eneco DEP |
| Oostpolder | Gem. Papendrecht; Eneco; Eneco DEP |
| Ouverture | Gem. Goes; Essent; Essent Warmte; Heijmans; ELES |
| Overdie | Gem. Alkmaar; Essent; Essent Warmte; ELES |
| Parijsch | Gem. Culemborg; Nuon Warmte; Nuon Warmte |
| Polderwijk | Gem. Zeewolde; Essent; Essent Warmte; Heijmans; ELES |
| Purmerend | Gem. Purmerend; Stadsverwarming Purmerend; Nuon ET&W; A. Hak |
| Reuver | Gem. Almelo; Cogas B.V.; Cogas Duurzaam |
| Rijpelberg/Brouwhuis | Gem. Helmond; Wamob; Essent Energy Trading |
| Rijtuigweg | Gem. Bergen op Zoom; Essent; Essent Warmte; Heijmans; ELES |
| Roombeek | Gem. Enschede; Essent; Essent Warmte; ELES |

| **Project 'name'** | **Actors** *(table 11 continued)* |
|---|---|
| Rotterdam | Gem. Rotterdam; Eneco Warmte; E. On |
| Schoonoord | Gem. Velp; Nuon Warmte; Nuon Warmte |
| SV Huttenweg | Gem. Almelo; Cobas B.V.; Cogas Duurzaam |
| Utrecht - Leidse Rijn | Gem. Utrecht; Eneco Warmte; Nuon ET&W |
| Utrecht - Nieuwegein | Gem. Utrecht; Eneco Warmte; Nuon ET&W |
| Utrecht - Stad | Gem. Utrecht; Eneco Warmte; Nuon ET&W |
| Vaanpark | Gem. Barendrecht; Eneco; Eneco DEP |
| Vathorst | Gem. Amersfoort; Eneco; Eneco DEP |
| Veenendaal | Gem. Veenendaal; DEVO; Heijmans |
| Vijfwal | Gem. Houten; Eneco; Eneco DEP |
| Waalsprong | Gem. Nijmegen; Nuon Warmte; Nuon Warmte; Nacap; BAM; VSH |
| Wageningen | Gem. Wageningen; Nuon Warmte; Nuon Warmte |
| Wateringseveld | Gem. Den Haag; Eneco; Eneco DEP |
| Waterwegcentrum | Gem. Hoek van Holland; Essent; Essent Warmte; Heijmans; ELES |
| Westpoort/Nieuw West | Gem. Amsterdam; Westpoort Warmte; AEB; Nacap |
| Wezenland | Gem. Deventer; Essent; Essent Warmte; Heijmans; ELES |
| WKK's Amsterdam | Gem. Amsterdam; Nuon Warmte; Nuon Business |
| Ypenburg | Gem. Den Haag; Eneco Warmte; Eneco DEP |
| Zandvoort | Gem. Zandvoort; Nuon Warmte; Nuon Business |
| Zuid/Zuidoost/Ijburg | Gem. Amsterdam; Nuon Warmte; Nuon ET&W; A. Hak; VSH; Nacap |
| Zuidbroek | Gem. Apeldoorn; Essent; RWZI; BAM |

## 11.7 Large version of the Dutch BioGrid network

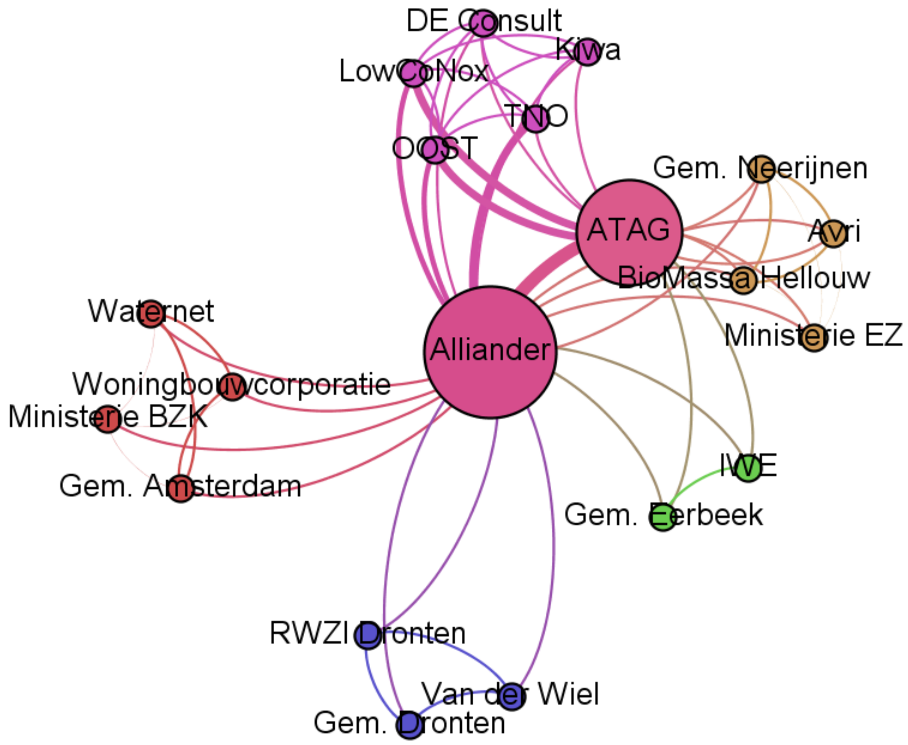


Figure 13: Large version of the BioGrid network of the actors in the investigated projects (see Figure 7).

## 11.8 Large version of the District Heating network

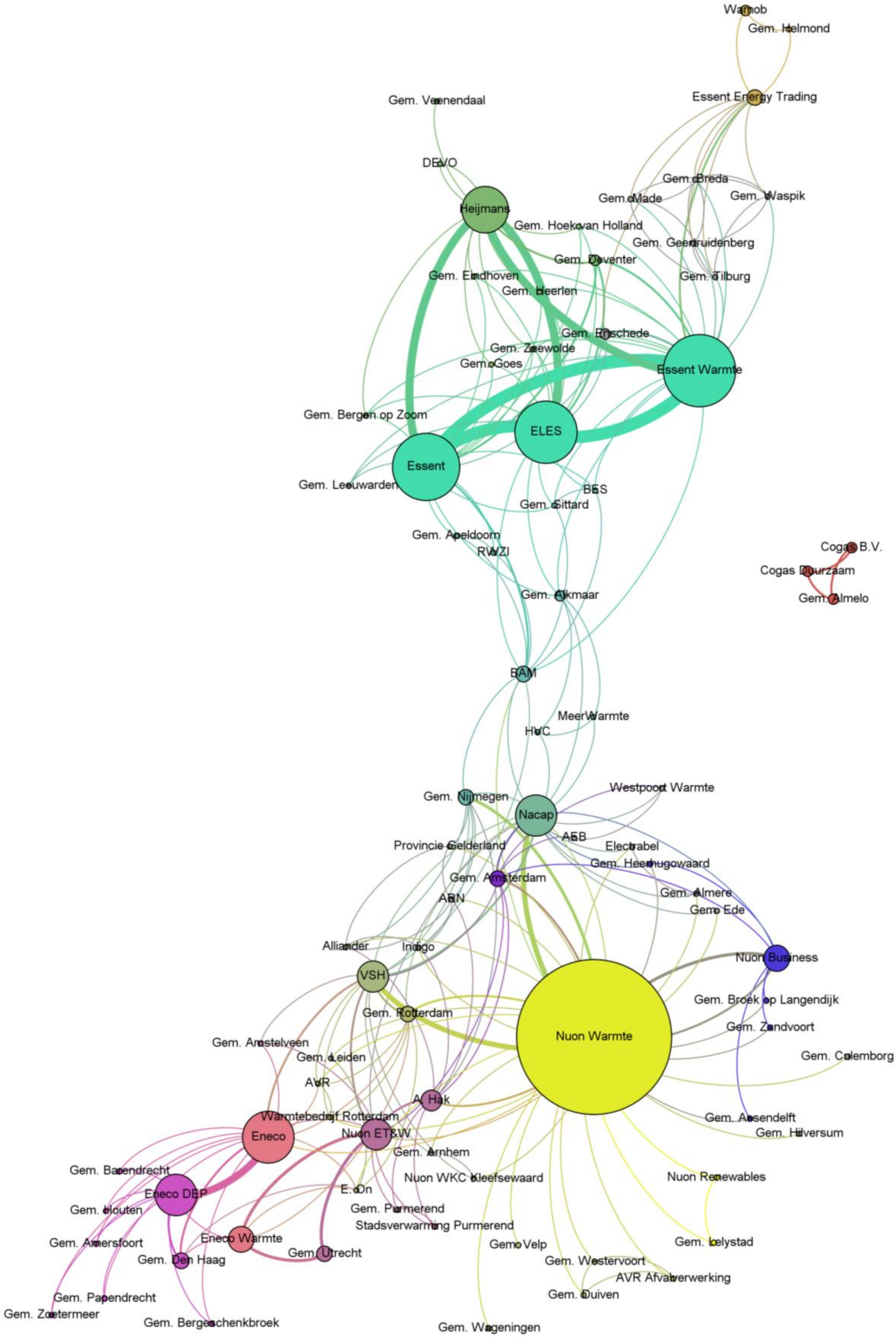


Figure 14: Large version of the District Heating network of the actors in the investigated projects (Rotated 45 degrees counter-clockwise compared to Figure 9).

## 11.9 Event History Analysis results per TIS function for District heating

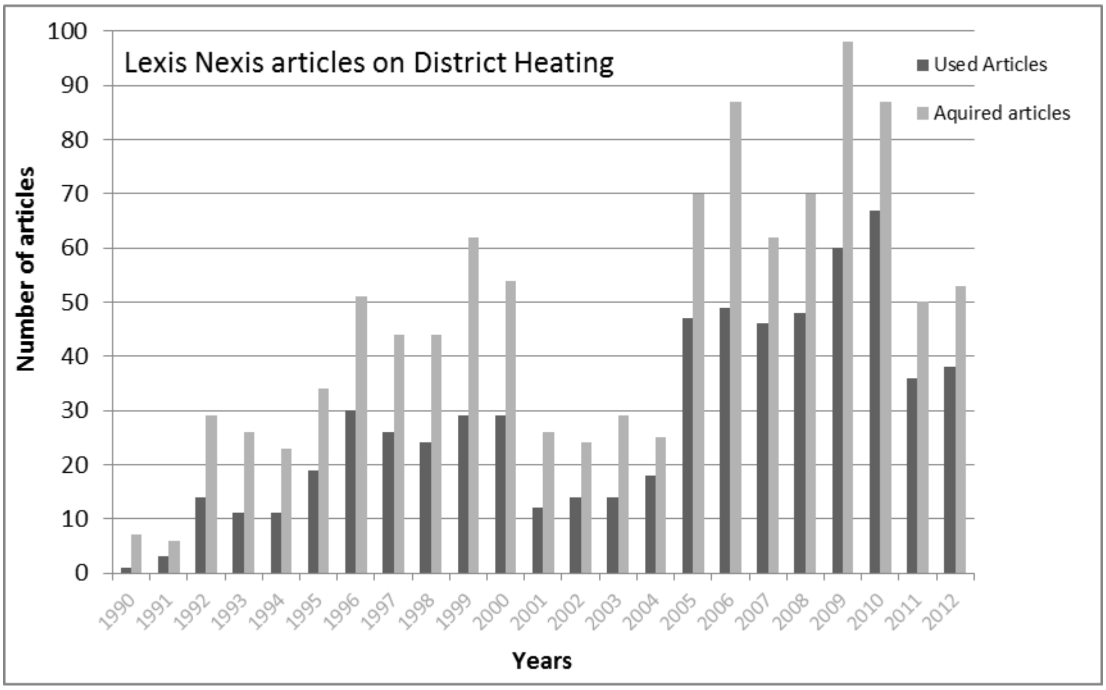


Figure 15: Large version of the bar graph on the number acquired articles in the Lexis Nexis search (see section 3.2 and 3.4.1) and the number of articles actually used in the Event History Analysis per annum. The bars per year represent the number of articles. This limits the maximum impact per function per year and hence the article drop over the period 2001-2004 directly influences the results and should therefore be taken in consideration. The underlying raw Event History Analysis data can be provided after contacting the thesis researcher, contact info is found on the title page.

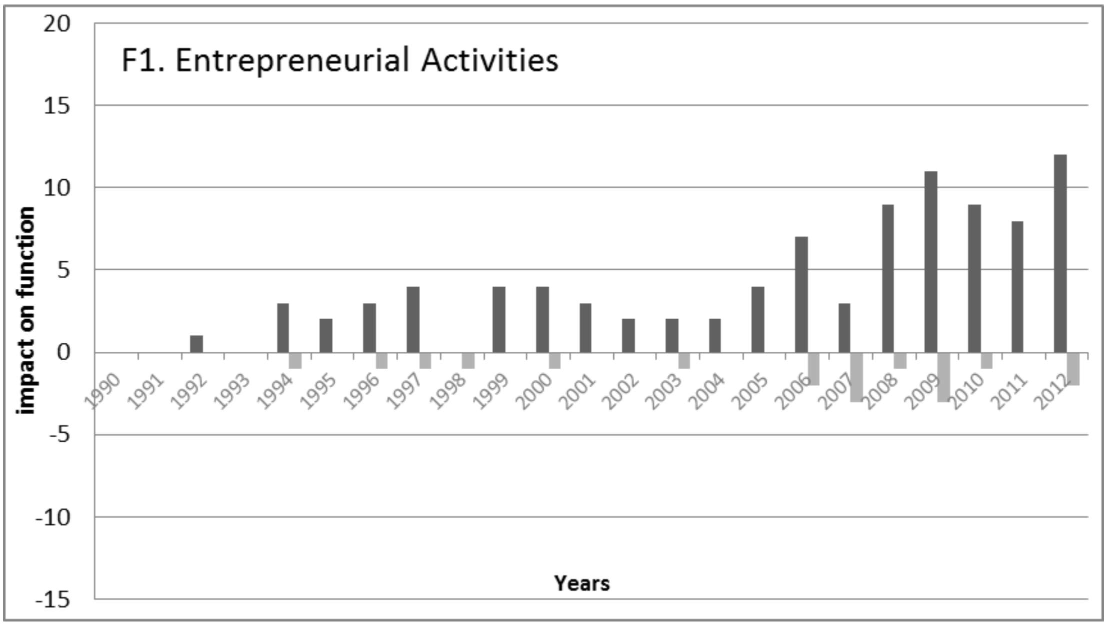


Figure 16:Event History Analysis results for Function 1: Entrepreneurial Activities. This graph shows a rise of the projects started and initiated in the last decade for Function 1. Consequently F1 seems to be functioning properly according to what to expect from the phase of development of the technology.

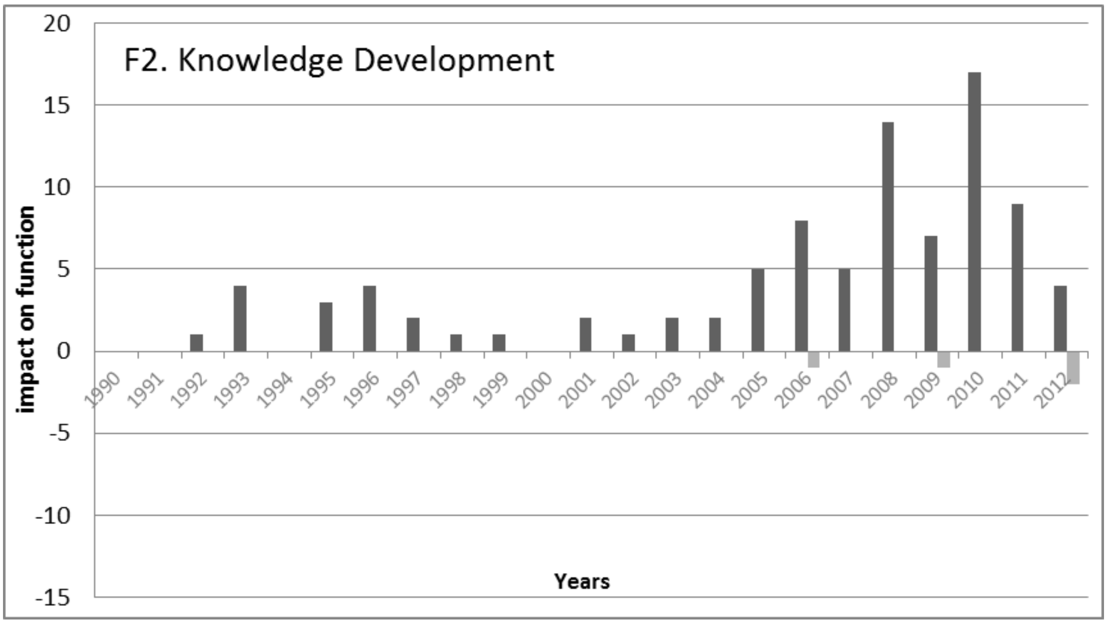


Figure 17: Event History Analysis results for Function 2: Knowledge Development. This graph shows that there were numerous reports of studies and trails for DH, especially over the last decade. Consequently, it could be said that F2 seems to be functioning suitably according to what to expect in the development phase, however the technology is currently in the take-off phase and thus other functions are more important, such as Entrepreneurial Activities (F1) and Creating of Legitimacy (F7)

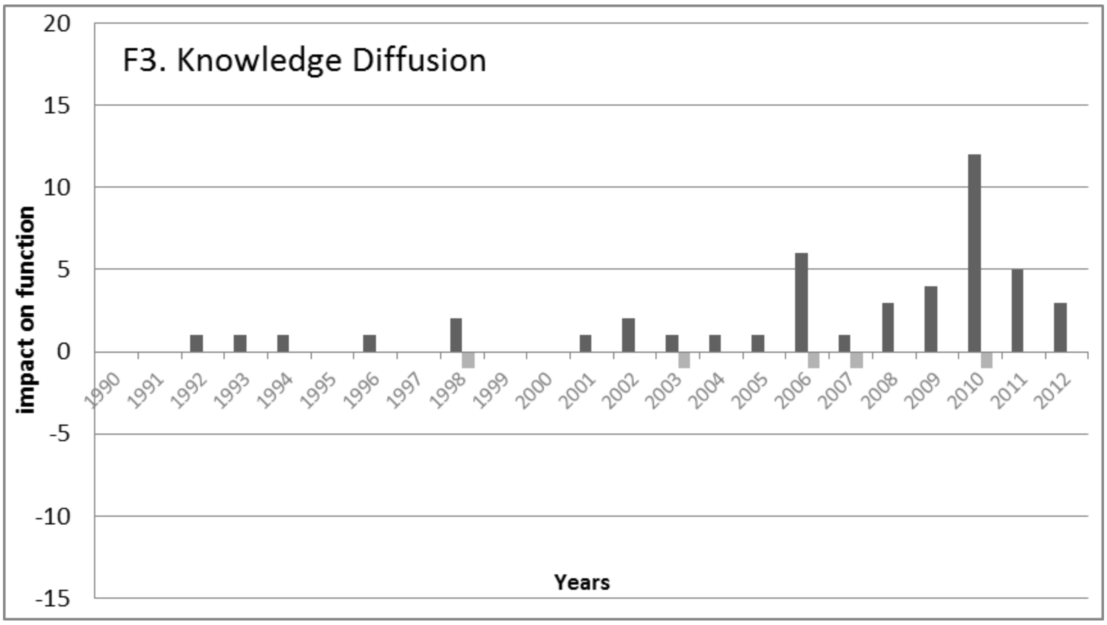


Figure 18: Event History Analysis results for Function 3: Knowledge Diffusion. The data reported of limited conferences, workshops, and alliances. Subsequently F3 might form a limiting factor that requires more attention when targeting to move from the Take-off into the Acceleration phase of the DH innovation system.

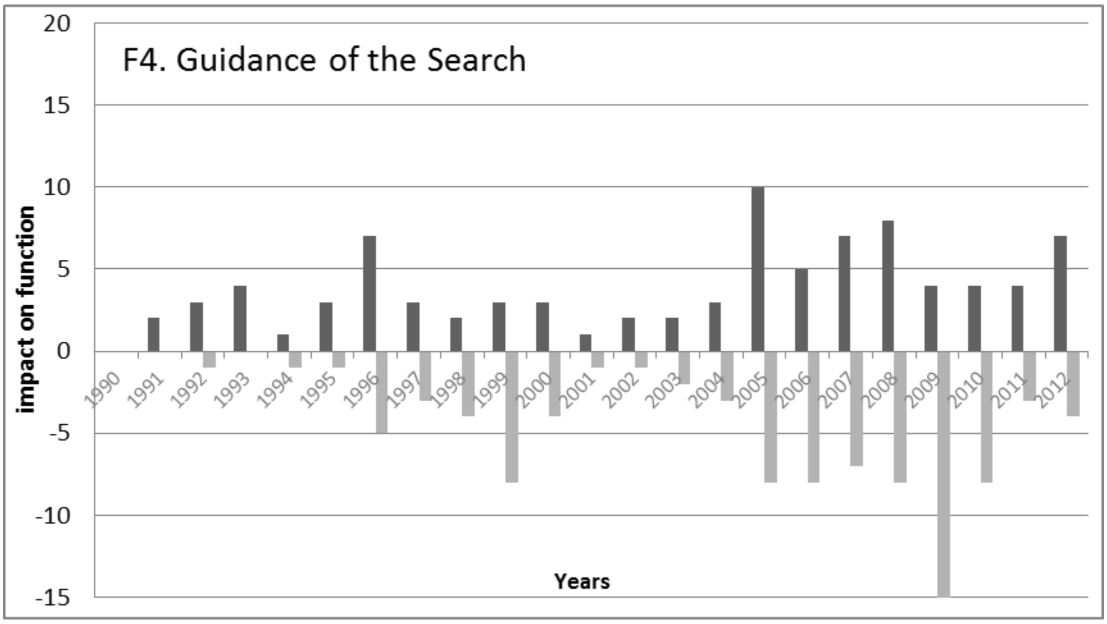


Figure 19: Event History Analysis results for Function 4: Guidance of the Search. Reports on promises, expectations of the technology, and policy targets in line with the technology show to be ambivalent. This indicates a potential deficit in governmental regulations and negative expectations of the technology.

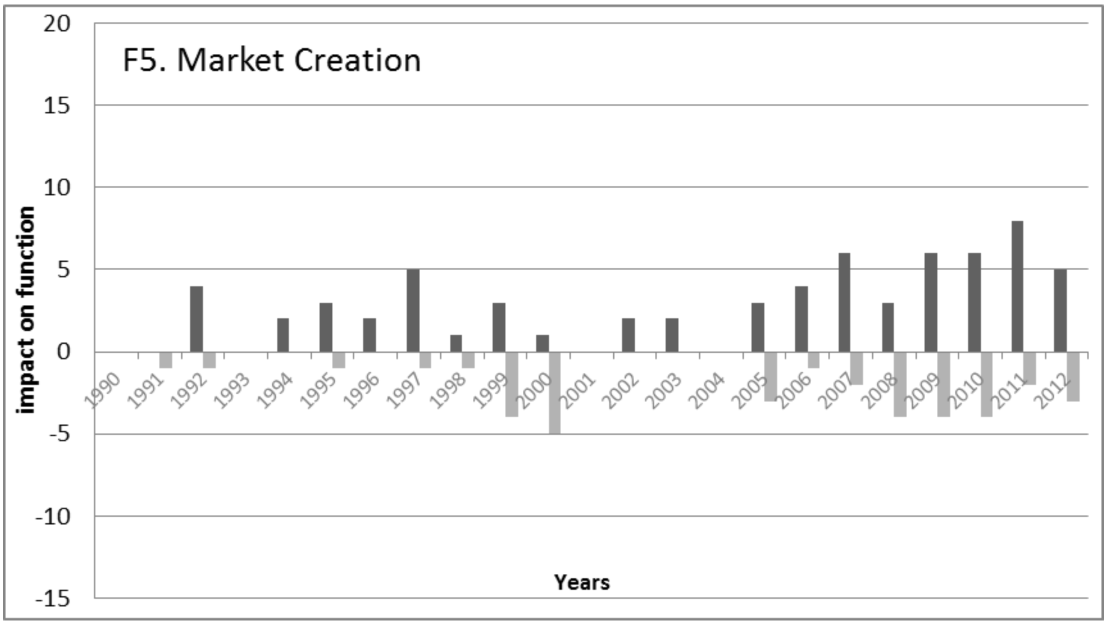


Figure 20: Event History Analysis results for Function 5: Market Formation. Market parties and the government are seemingly unclear how to progress. Market actors indicate a lack of favourable tax regimes for DH and are against the roll out of the heat law. On the other hand, there are uncertainties on how environmental friendly District Heating actually is. In the Acceleration phase F5 is an important function and this provides direction for the identification of barriers to the development of the DH innovation system.

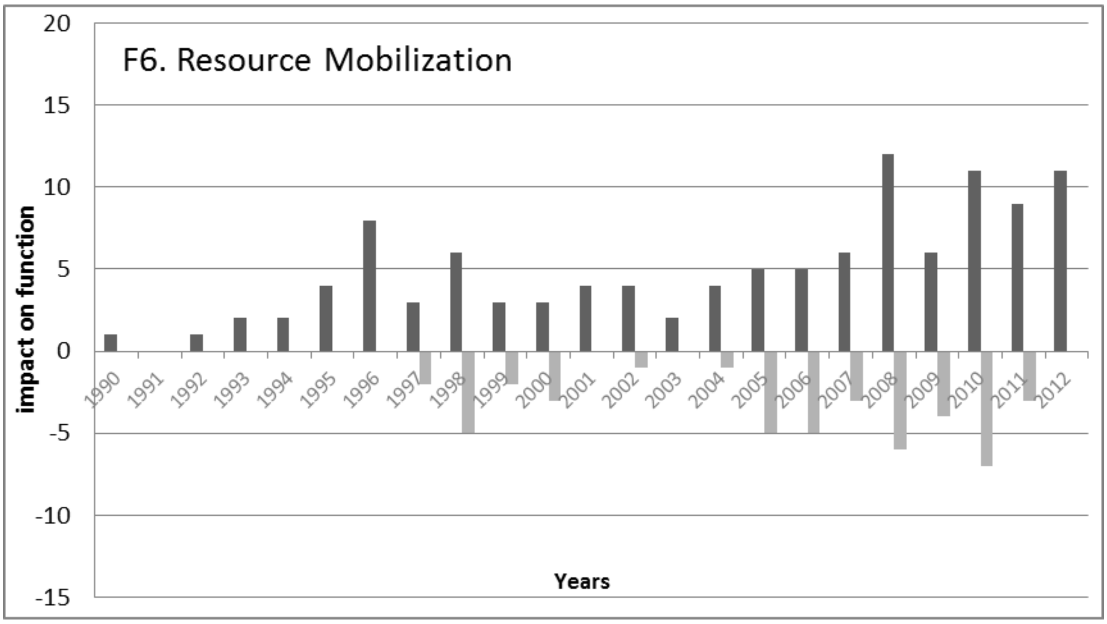


Figure 21: Event History Analysis results for Function 6: Resource Mobilisation. The Netherlands is not known for stable subsidy schemes and in the current economic climate one would expect difficulties in finding funding for Dh projects. However, in the last 15 years green funds have started to accumulate money and are keen to invest. The availability of residual heat streams and contracts with ‘producing’ and ‘supplying’ party form potential issues.

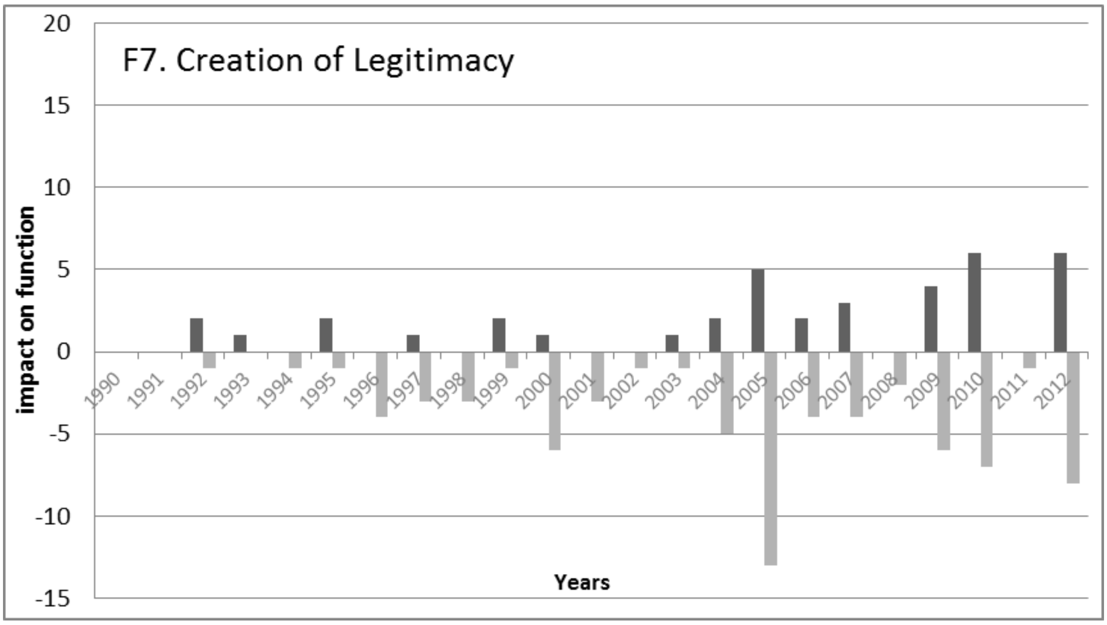


Figure 22: Event History Analysis results for Function 7: Creation of Legitimacy. This Function shows to be the least functioning factor. Society is not undisputedly positive about the technology; nevertheless there are expectations of the environmental impact of DH compared to the use of gas condensing boilers. However, negative tendencies related to the billing schemes will hold back the willingness to use DH technology from a consumer’s perspective. There is an expressed lack over government support that should have been captured by the heat law, however this law keeps being postponed for – to the general public – unclear reasons.

### 11.10 Cummulative results of the Event History Analysis

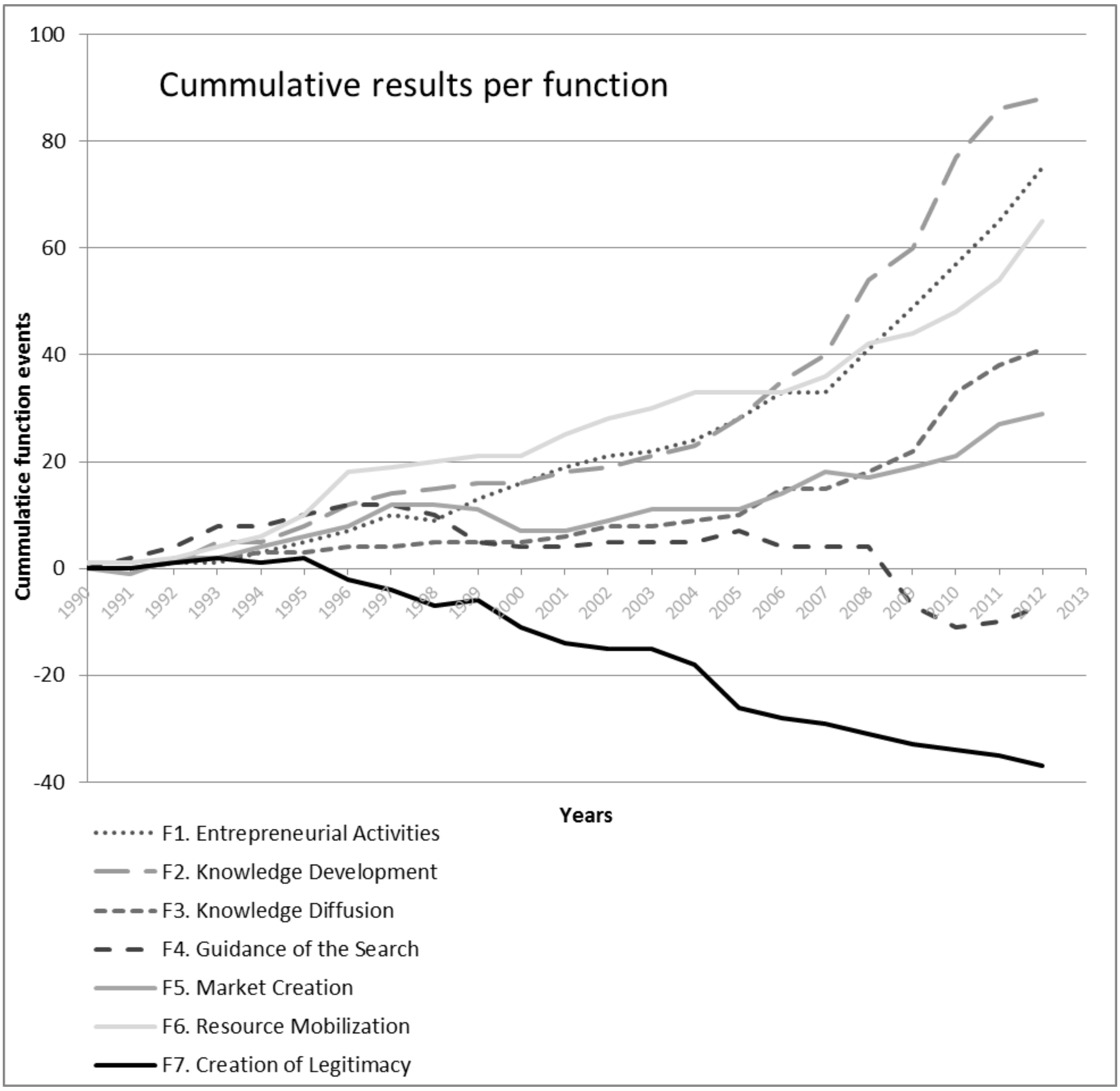


Figure 23: visualisation of the cumulative results per function over the period 1990-2012. Function 1, 2, and 5 show proper innovation system development. Function 4 and 5 are somewhat hampering factors for DH development and are potential starting points to look into. Function 4 and 7 are more a source of concern. Guidance of the Search (F4) declined over the past 5 years, but Creation of Legitimacy (F7) shows to be a problematic factor since halfway the 90's. For the move from the Take-off phase towards an Accelerating mode, especially the Functions 5 and 7 needs to be taken care of (see Figure 3 for the important system interactions per phase of TIS development)

## 11.11 Dutch Domestic heat demand in GJ per annum

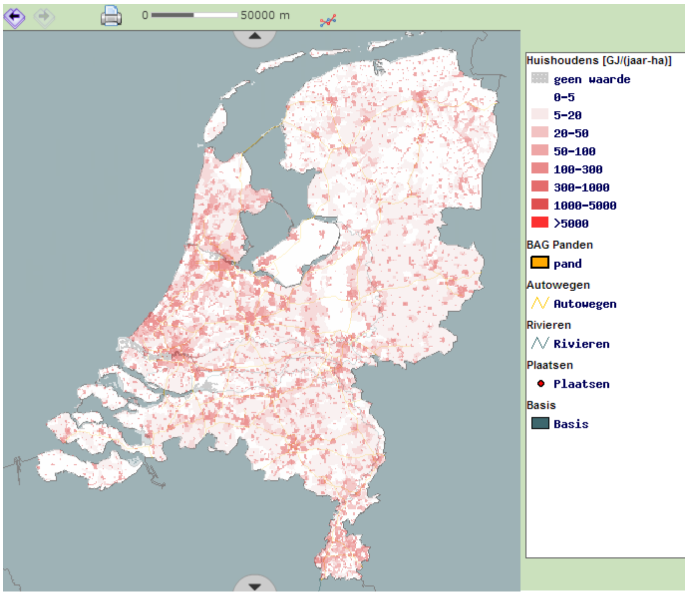


Figure 24: Map of domestic heat demand in the Netherlands in GJ/(year*ha) the higher the demand the more likely the location is beneficial to BioGrid and District Heating development (WarmteAtlas.nl, 2013).

## 11.12 Residual heat potential in the Netherlands in TJ per annum

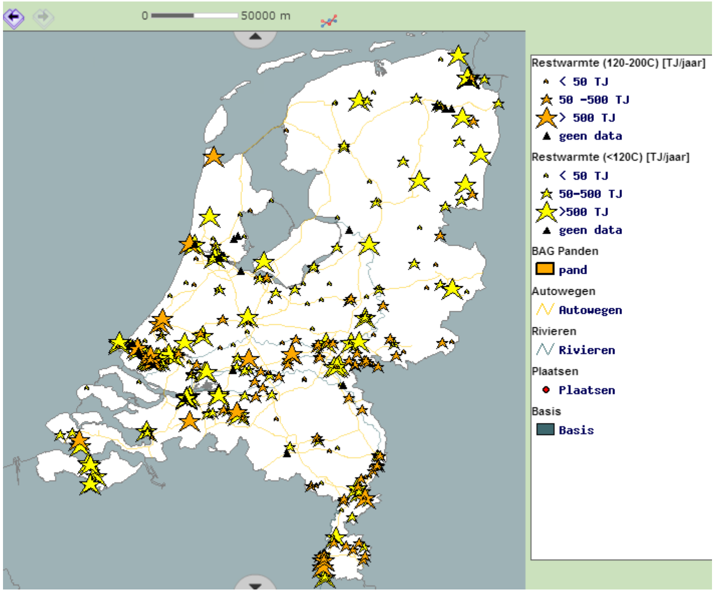


Figure 25: Map of residual heat potential in the Netherlands in TJ/year, these are potential streams with can benefit District Heating development (WarmteAtlas.nl, 2013).

## 11.13 Geothermal potential beneficial for DH

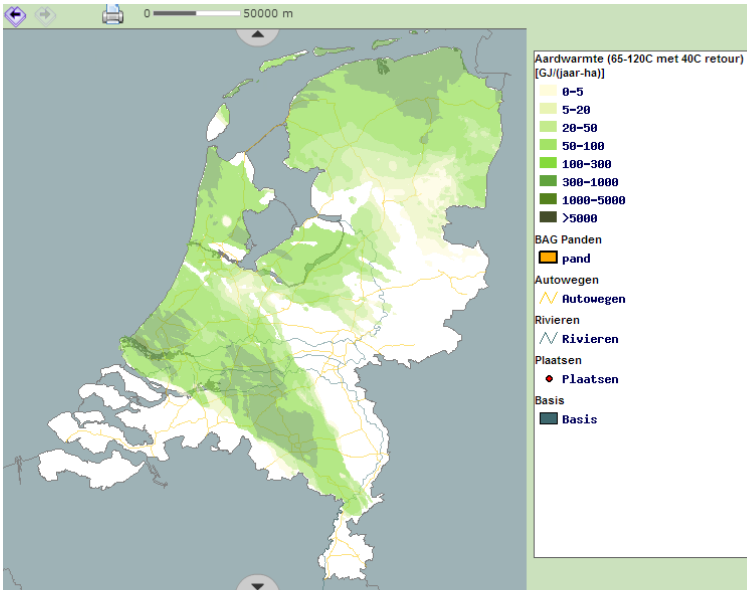


Figure 26: Map of geothermal potential for aquifers of 65-120 °C with 40 °C return stream in GJ/year (WarmteAtlas.nl, 2013).

## 11.14 Dutch biogas potential

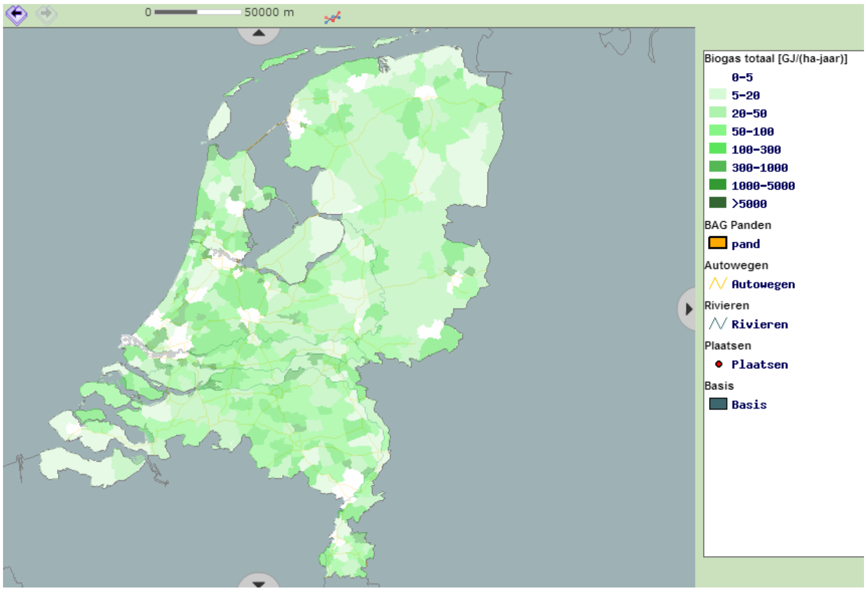


Figure 27: Map of total biogas potential in the Netherlands in GJ/(year*ha) to benefit BioGrid development (WarmteAtlas.nl, 2013).

## 11.15 BioGrid potential up until 2020

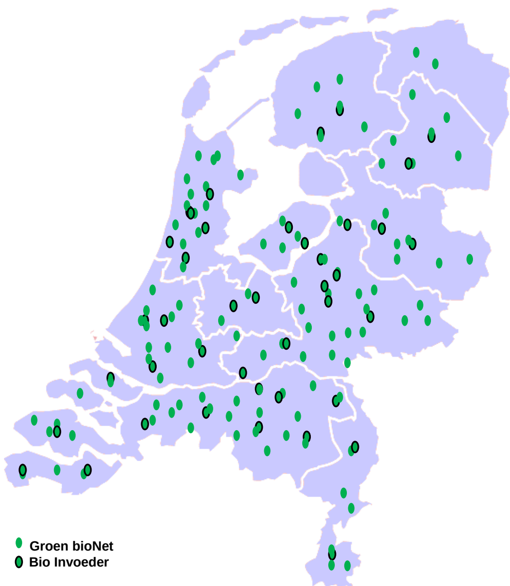


Figure 28: Map of theoretical BioGrid potential from now until 2020, this is potentially is 254 kTon/yr of $CO_2$-emision reduction in the Netherlands (Alliander, 2011). This potential is a representation of what the dispersion and impact could be.