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The transition to active distribution networks in the Netherlands: an innovation system and network analysis

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The transition to active distribution networks in the Netherlands: an innovation system and network analysis

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Abstract:

In recent decades the integration of decentralized generation of electricity has grown rapidly, causing an increasing strain on local distribution networks. Although literature reasons that current regulations hamper the transition to active distribution networks, which can better deal with the implementation of DG, we take a broader perspective in this study to see whether there are any other barriers to the transition. We have therefore studied the transition to active distribution networks using a technological innovation system approach in combination with a social network analysis. Our results show that, even though the regulations are indeed unfit to support the transition, there are also other factors at stake. We have found that there is strong need for more pilot and demonstration projects that help solve important social and economical questions, which in turn should help to create a shared vision in the system and can provide guidance for a revision of the laws and regulations. In addition we have found that there should be more attention for the needs and characteristics of the end users and that a more proactive government could help to raise the sense of urgency for the transition.

1.Introduction

In recent decades the attention for distributed generation (DG) has increased significantly, mainly spurred by objectives from the EC which demand an energy consumption reduction of 20% by 2020, a reduction of greenhouse gas emissions of 20% in comparison with the 1990 levels and the production of at least 20% of the electricity with Renewable Energy Sources (RES). In addition the 2009 EC directive promotes the implementation of DG as a means to facilitate the increased usage of RES. Having been the primary source for power generation almost a century ago, decentralized generation now gains renewed attention due to these recent developments in EU goals. In this paper we shall use the definition by Ackermann et al. (2001) which states that DG is "*[…] an electric power source connected directly to the distribution network or on the customer site of the meter*". This also largely corresponds with the definition provided in the 2009 EC directive, which defines DG as *"[…] generation plants connected to the distribution system"*. According to these definitions an important prerequisite for DG is that it is connected to the distribution system. This makes the integration of DG into the electricity network an important task for the distribution system operator (DSO), which is in charge of operating the distribution network and is as such responsible for connecting DG to the grid.

The increasing implementation of DG in the current electricity infrastructure is already in progress on different scales in EU member states. According to figures from 2004 the five EU member states with the highest penetration of DG are Denmark, Germany, Sweden, Spain and the Netherlands (Cossent et al., 2009). A transition to increased penetration of DG knows both drivers and challenges. Lopes et al. (2007) mentions some important drivers that stimulate the increasing penetration of DG. Distributed generation can help achieve the energy and climate goals set by the EU, as DG can comprise energy saving or sustainable energy technologies that help reduce the emission of greenhouse gasses and it can help avoid the construction of new large generation plants and transmission circuits. Commercially, the construction of smaller generation plants might pose less financial risks for retailers in a liberalized market. And from a regulatory point of view DG can enhance the energy security by diversifying the mix of energy sources and it can improve the quality of service due to an increased number of players and competition.

But an increased penetration of DG can also pose some challenges for the electricity system. According to Lopes et al. (2007), there is a risk for power stability and quality problems when DG is integrated in the distribution grid. Financially, connecting DG can possibly lead to increased costs for the DSOs, depending on whether they rely on deep or shallow charging[1]. A final challenge is that due to the course of history the majority of post-world war distribution systems were planned and developed into passive distribution networks, mainly organized to supply bulk power from large generator plants to low voltage consumers. Within these passive networks DG is integrated by conventional network reinforcements (increasing the copperplate) (Bolton et al., 2010), an approach that has also been dubbed as 'fit and forget'. This approach is often very costly since the network has to be upgraded to meet times of peak demand that only occur very rarely. In order to permeate this 'fit and forget' impasse and to make more efficient use of the physical assets, a socio-technical transition to an active distribution network, organized to more efficiently facilitate the increased penetration of DG, is desirable.

The need for this transition and the important role of an active distribution network for the increased penetration of DG has been underlined by numerous authors (e.g. Hindsberger et al., 2003, Overbeeke et al., 2002, Joode et al., 2010, Frias et al., 2008, Lopes et al., 2006, Djapic et al., 2007, Strbac et al., 2009, Ochoa et al., 2010, Bolton et al. 2010, etc.). Within this paper we use the definition by Liew et al. (2002), who defines an active distribution network as "[…] *a network where real-time management of voltage, power flows and even fault levels is achieved through a control system either on site or through a communication system between the network operator and the control devices*". Another term that is often heard when talking about grid modernizations is '*Smart Grids*'. We will refrain from using this term in this research as much as we can, as it has been used in many different contexts with many different meanings and might therefore work confusing in academic context.

To realize an active distribution network enormous amounts of investments are required in both power equipment and ICT infrastructure to allow a more efficient use of the existing network capacity (The Brattle Group, 2009). Also, consumers and distributed generators connected to the network are to become actively involved in facilitating the operation and planning by the DSO (Joode et al, 2010). The transition to an active distribution network changes the role, position and mental model of a DSO, it changes the way consumers use electricity and it changes the way generators are integrated in the network. These changes are so radical that it can be seen as a paradigm innovation (Francis and Bessant, 2005), a classification that has also been used by various other authors for the transition to active distribution networks (e.g. Frias et al., 2007, Jansen et al., 2007, Cossent et al., 2007).

At this point, literature has mainly investigated the role of the regulatory framework in relation to the penetration of DG (Woodman et al., 2008), and later on also the relation between regulation and innovation (Meeus, 2010), making the assumption that innovation in the distribution grid is a prerequisite to increase the penetration of DG. Mostly the conclusion is drawn that, due to faulty or inadequate regulatory frameworks, DSOs are lacking incentives to innovate their network infrastructure and to make the transition to an active distribution network. Joode et al. (2010), for example, have shown in their research that integrating DG in an active distribution network under existing regulatory frameworks does not result in lower costs for the DSO and therefore does not provide the right incentives to start innovating. In addition, Niesten (2010) also shows that the current regulatory framework in the Netherlands mainly stimulates DSOs to reduce their capital and operation costs, whilst failing to provide incentives for investment in active distribution networks. This strand of literature thus pleads for a change in

[1] Deep charging allows the DSO to recover all the costs made for connecting DG to the grid. In the case of shallow charging part of these costs are socialized on all users connected to the grid, causing an overall increase of distribution costs.

regulations making investments in network innovations financially rewarding for DSOs.

The widespread focus of this strand of literature on the regulatory frameworks as the primary obstacle for network innovations can be easily explained. A distribution system operator is considered a 'natural monopolist', a concept which is explained by Carlton and Perloff (2004) as follows: "*When total production costs would rise if two or more firms produced instead of one, the single firm in a market is called a natural monopolist*". According to Newbery et al. (1996) this is the case for DSOs, since letting two DSOs operate in the same area would require the construction of two separate infrastructures. As a natural monopolist the DSO is free from market competition and therefore has to be subjected to a regulatory framework in order to prevent certain economic performance problems, such as excessive prices, production inefficiencies, etc, but also to provide the right incentives for efficient investment in the electricity infrastructure (Joskow, 2005). The importance of this regulatory framework in guiding the behavior of the DSOs can explain the focus of scholars on the regulatory framework when addressing the transition to an active distribution network.

It can be questioned, however, whether merely adjusting the regulatory framework is sufficient to stimulate the transition to an active network approach, an issue which has already been raised by various scholars. Keller and Wild (2004) question whether regulations are suitable for steering long-term investments in the electricity sector and plead to make these investments using a coordination group of all parties involved. Bauknecht et al. (2007) states that in realizing a network transformation it might be "*necessary to rethink network regulation as a whole, rather than merely changing some parameters*" and Cossent et al. (2009) already notices that "*it is still unknown to what extent performance based regulation can promote innovation by itself*". This type of question, in a more general manner, originates from the neo-Schumpeterian economics literature. The neo-Schumpeterian economists reject the idea that innovation is the result of a simple production function, including the amount of R&D spending (Nelson & Winter, 1977), or in the case of distribution networks, the result of economic incentives from regulation. Instead they stress the uncertainty involved in the process of innovation, the importance of 'learning-by-doing' and' learning-by-using', the cumulative nature of technology and the importance of individual innovators. Following evolutionary economics, innovation is bound to technological paradigms which, according to Dosi (1988), "*define the technological opportunities for further innovations and some basic procedures on how to exploit them along technological trajectories*". Applying this to the distribution network would imply that the current situation has been historically developed over the years and does not allow for the rules of the game to be changed overnight. Making the shift to an active distribution network, thus realizing a paradigm innovation, is therefore not something that can be settled lightly. Considering these insights from neo-Schumpeterian and evolutionary economics it seems even more unlikely that regulations are the sole limiting factor in transforming the distribution network.

We therefore propose that it is necessary to study the transition from a broader perspective than has been done so far. Instead of only looking to regulatory issues that might hinder the transition to active distribution networks, this paper aims to find other or additional barriers that are blocking the transition. This leads us to the following research question:

What are the barriers for the transition to an active distribution network?

We shall answer this question for the Netherlands, but the answer can also be relevant for other EU member states, as the organization of the electricity sector in member states is regulated by the EU. The transition to active distribution networks shall be studied from an innovation systems perspective in combination with a social network analysis. The innovation system perspective is a heuristic framework that allows one to study technological change from a broad perspective and that respects the fact that innovation doesn't happen in isolation, but rather depends on the system that surrounds it. The transition to active distribution networks happens in a complex system that consists of many different stakeholders and institutions and changes the function of the distribution grid in a fundamental way. Therefore the innovation system approach is an appropriate choice to study the transition for barriers to innovation. Combining the innovation system theory with a social network analysis is a rather novel approach and allows to expose a lot of activities, system actors and mutual relations in a clearly structured fashion and can therefore give a very broad and comprehensive picture of the innovation system. This ensures a more thorough analysis of barriers in all the aspects of the innovation system. Because of this broad scope we prefer to use the social network analysis over other methods of analysis used in innovation system case studies. For example, the event history analysis (a method proposed in Hekkert et al., 2007), is more focused on a chronological analysis of the innovation system and is therefore not optimal for this research, since the transition to active distribution networks is a topic that has become relevant only very recently. Therefore an analysis that focuses on the development of the system over time will not be appropriate here.

By identifying the barriers to innovation, this research contributes to the existing body of mainly economically oriented literature on the topics of distributed generation, distribution network investments and DSO regulation, by introducing an innovation-oriented perspective. In addition, it can help policymakers to widen their focus beyond just regulatory measures, allowing them to also address other barriers that might play a role in hampering the transition to active distribution networks.

In the following chapter, the theory of innovation systems and the social network analysis and its implementation in this research shall be further elaborated on. In chapter three the methodology and scheme of analysis for studying the technological innovation system for active distribution networks is further elucidated upon. Then the results will be presented and an analysis of these results will follow, after which this paper will finish with a conclusion and a discussion.

2. Theoretical framework

The innovation systems approach studies technological change from a system perspective and treats it as an endogenous factor, allowing it to co-evolve with the other economic activities within the system. The concept of an innovation system can be explained as a system wherein technology[2] is generated, diffused and utilized by a network of actors within an institutional environment. The system can be delineated by various boundaries, such as national, regional, sectoral or technological boundaries. Since we are studying the transition of the distribution network, we shall focus on the technological innovation system (TIS) approach, which was first described and developed by Carlsson and Stankiewicz (1991). The scope of a TIS can, depending on whether the technology is generic or specialized, range from rather broad to very narrow. A technological innovation system consists of three structural components, which are *actors*, *networks* and *institutions*. The *actors*, which are the DSOs, electrical engineering firms, research institutes, governmental organizations, etc, interact with each other through both formal and informal *networks* and are limited and guided in their actions by the *institutions,* which are regulations, laws

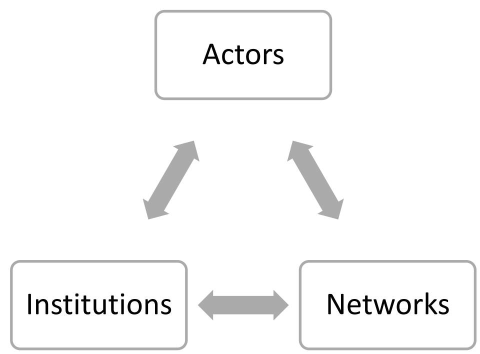

Fig. 1: *structure of the technological innovation system*

and normative structures. These three components are the building blocks or foundation of the innovation system and describe the relevant environment in which a technology is being developed and implemented. Of course an innovation system is not a static concept that can be described by merely looking at the structural components. If one wants to investigate the determinants of technological change it is not sufficient to know which actors are involved and what kind of institutions are present. Instead, innovation systems are highly dynamic, meaning that there are a lot of interactions in the system and that there are a lot of different processes that take place. To respect this dynamical nature of the innovation system and to get to know what is actually happening within the system, one needs to study these processes and interactions, or so-called *system dynamics,* as well. Examples of system

[2] By technology we do not only mean the hardware components, but also the more soft aspects of technology, such as knowledge and competences.

dynamics are, for example, regulations that might prevent certain actors from entering the system and actors that organize themselves in networks that try to influence the institutional environment. Or the networks that help spread knowledge on new technological developments to industrial actors which in turn can decide to start a new venture. These system dynamics are omnipresent in innovation systems and have gained increased attention in recent literature (hekkert et al, 2007, Bergek et al, 2008). The *system dynamics* cannot be described or guessed by merely studying the building blocks of the innovation system. Different forms and attributes of the building blocks can still share similar *system dynamics* and lead to the same outcome of the innovation system (jacobsson, 2008), just as systems that share the same structural components could have different *system dynamics*. Scholars have come up with certain key processes or *functions* to catalogue those system dynamics that they consider to be essential for the generation, diffusion and utilization of the technology (e.g. Johnson, 2001, Bergek, 2002, Bergek et al., 2008, Rickne, 2000, Carlsson et al., 2005, Edquist, 2004, Hekkert et al., 2007). The innovation system itself changes, develops and grows over time. This happens due to non linear interactions between the *system functions* (Jacobsson et al., 2000). By influencing each other functions can trigger virtuous cycles that structurally affect the innovation system (fig. 2). By including these *system functions* and the interactions between them in our theoretical framework we pay attention to the dynamical nature of the innovation system.

Generally this means we can distinguish three different layers of analysis in the innovation system: the

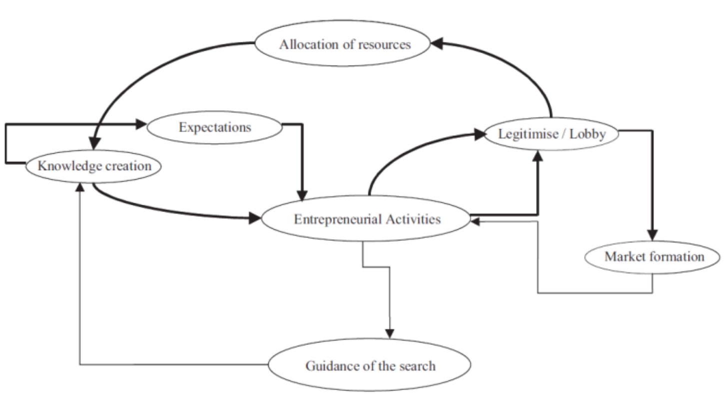

Fig. 2: *Possible interactions between system functions. Source: Hekkert et al. (2007)*

structural components, *the system functions* and the *interactions* between the system functions. All three layers define and affect the innovation system and need to be studied. The following example will better clarify these three layers: by looking at the structural components you might learn that the innovation system has a strongly connected actor network. By studying the system functions you might find that this densely connected actor network has led to a strong diffusion of knowledge. And by examining the influences between the system functions you might find that this strong diffusion of knowledge has grown a strong legitimacy among the system actors.

The core idea of the innovation system theory is that the structural system components, the system functions and the interactions between them can either hamper or foster the development of a technology. For example, just as a very interconnected network can help accelerate the diffusion and the development of a technology by spreading knowledge and information to all the system actors, a loosely interconnected network can pose a great barrier to just that (Kim et al., 2009). And just like widespread support for a technology can help to free up resources and create niche markets, poor (public) support can greatly hamper the availability of resources. The assumption that barriers in the innovation system can hamper the transition to active distribution networks has already been made earlier in the literature. Bolton et al. (2010), for example, argues that the mixed success in promoting innovation in the distribution network sector in the United Kingdom is mainly caused by poor system dynamics.

The broad perspective of the innovation system, taking into account *structural components* and the *system dynamics*, can reveal a lot of barriers to the transition to active distribution networks and is therefore a very suitable framework to help answer our research question. In the following section this theoretical framework will be further explained by describing and delineating the core concepts and by linking them to the framework. First the *structural components* will be clarified, including their theoretical foundation, and after that also the *system dynamics* are further specified in terms of *system functions* and the *interactions* between them.

2.1 Actors and networks

The first two system components, actors and networks, are taken together for further explanation here, since the two are highly related and will also be analyzed together in this research. With *actors* we mean firms, entrepreneurs, financial institutes, universities, governmental organizations, etc., that are operating within the innovation system. It is not assumed that these actors are all pursuing the same agenda, nor do they have to share the same goals. The main prerequisite for an actor to be part of the TIS is that the actor is somehow involved in the generation, diffusion or utilization of the technology.

The *networks* are formed by *actors* that engage in relations with each other, for example through alliances, research projects, conferences, etc. These collaborations and interactions can greatly stimulate the process of learning (Powell et al., 1996), as the creation of a network allows knowledge and competences to flow through the innovation system. Networks help to evolve and grow the innovation system over time (Kim et al., 2009), networks allow actors to become better aware of the system dynamics, reducing the amount of uncertainty, and networks are able to increase the mutual trust between actors, leading to a reduction in transaction costs (Jones, 1995). When these actors and networks are not properly organized, meaning that knowledge and information is not able to spread easily between the actors, it may pose a barrier to innovation in many ways. A sparse network could prevent actors from organizing themselves to put up proper lobby actions and could slow down the diffusion of knowledge. If a network consists of many different and loosely related clusters then these clusters might be doing the same efforts, while competing for the limited amount of available resources. Or they might develop different technological solutions for the same application, causing problems with multiple standards and uncertainty about which technological solution to choose. These problems can slow down the overall progress of the technological development. It are these kind of potential barriers that require us to analyze these actor networks. This can be done using social network theory. Social network theory is a valuable additive for the innovation system framework used in this research, since it offers a structural method of analysis of the actor networks. The following section will explain social network theory and how it is incorporated into the innovation system framework in this research.

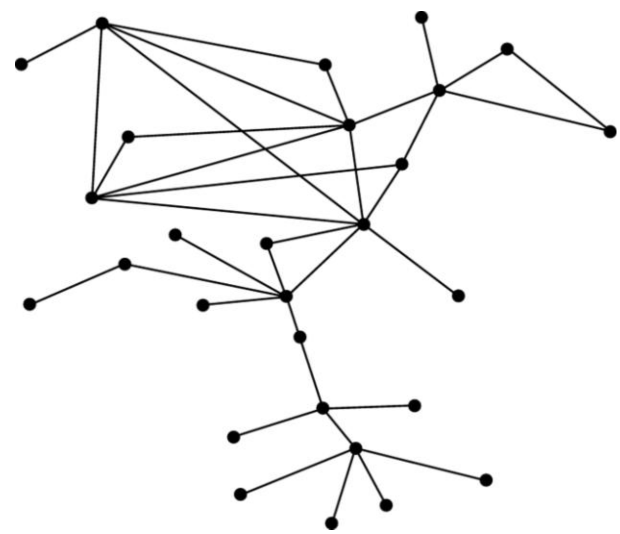

Fig. 3: *An example of a social network: the dots represent the nodes and the lines the ties between them*

2.1.1 Social network theory

Social network theory is an approach that studies social structures. These social structures are built up of 'nodes', e.g. individuals or organizations, and 'ties', i.e. the connections between those nodes (Wasserman et al., 1994). Together, these nodes and ties form a social network. According to Wasserman and Faust there are four important principles underlying these social networks. First, the actors within the network and their actions are considered to be interdependent, rather than independent units. Second, the relationships between actors are regarded as important channels to exchange knowledge, competences, goods and services. Third, the structural network environment of actors is considered either an opportunity or a constraint from the perspective of an individual actor. And finally, the structure of the network is conceptualized as a lasting pattern of relations among actors.

Even though social network theory was originally used within the social sciences, research in many different fields has shown that these social networks can also be found on a number of different levels, for example between organizations, individuals and nations. It has even been successfully used earlier in studying socio-technical networks (e.g. Gay and Dousset, 2005, Cantner and Graf, 2004). Therefore, social network theory offers interesting opportunities to study actor networks as can be found in an innovation system. As explained in the previous section actors in an innovation system collaborate with each other and form (in)formal networks through which knowledge and technology can be diffused. The layout of such a network, thus the actors and the connections between them, is called the network structure. Since one of the underlying principles of social network theory is that the network structure can either be a constraint or an opportunity for individual actors, it is necessary to analyze the network structure for potential barriers. Social network analysis allows to study this network structure for potential constraints or barriers, as it offers a wide range of statistical 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. Kim et al. (2009), for example, already showed that an on average close link between actors and a high degree of network density can greatly stimulate innovation within an actor network. And Gay and Dousset (2005) point out that individual firms can profit from a central position in the network. The exact measures that are used for the network analysis in this research are explained in the methodology.

Using a theoretical approach like the social network theory to study concepts from innovation system theory cannot be done without strong considerations on their conceptual compatibility though. Both theoretical frameworks will need to rely on the same underlying assumptions to be able to be used together. In this case this means that social network theory needs to share the same assumptions about the two concepts *actors* and *networks* as the theory of innovation systems. To begin with, both theories have in common that they heavily emphasize not the importance of 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 pawn without many opportunities as long as it does not interact with other actors in the system. Also the underlying principles of the social networking theory correspond largely with those of the innovation systems theory. Both agree on the interdependent nature of the actors within the system, the importance of networks to diffuse knowledge and competences and the ability of networks to constrain or stimulate individual actors. Only the fourth principle of social network theory, the focus on lasting patterns of relations, is taken somewhat broader in the innovation systems literature, where also incidental interactions between actors are considered to be part of the system dynamics. Finally, social network theory has been used earlier in explaining the diffusion of innovation (Deroïan, 2002) and has also been used earlier in combination with the theory of innovation systems (van Alphen et al., 2010). Using both approaches together for this research will provide a more effective framework to study the totality of the technological innovation system, allowing to analyze both the structural as well as the dynamic aspects of the innovation system.

2.2 Institutions

The third and final building block is formed by the *institutions*. The institutions can, according to North (1990) be divided into two categories. These are formal and informal institutions. The informal institutions are normative structures, that govern the actors, their actions, expectations and interactions within the innovation system. On the other hand there are the formal institutions, the laws and regulations. The institutions can help provide certainty by structuring various processes within the innovation system, but can also be an important barrier to innovation by blocking these processes instead. One example of formal institutions blocking innovation could be the regulatory framework for DSOs mentioned in the introduction. But also cultural, political or ethical factors are able to hamper the technological development. Take for example genetic engineering, where "*Ethical concerns play an important role in public reactions to genetic engineering*" (Frewer et al., 1997) or the stem cell research in the United States, which became the subject of a political debate (Weissman, 2002).

2.3 System functions and interactions

As explained before the system dynamics are important processes in the innovation system and are considered essential for the generation, diffusion and utilization of the technology. The system dynamics represent what actually happens within the system. Examples of these system dynamics are actors that use their network to form a more efficient lobby to plea for more resources or better regulations. Or knowledge that diffuses through the system with the help of the actor network. Scholars have attempted to catalogue these system dynamics in a set of key processes or *system functions.* These *system functions* should cover those *system dynamics* that are crucial for the successful development and implementation of a technology. Examples of such functions are the development of knowledge or the availability of resources. As has been shown in several studies, barriers or failures in one or more of these system functions can cause the innovation system to collapse (Kamp et al., 2004., Negro et al., 2006., etc), just as well as properly developed system functions can greatly foster the success of technological development. Scholars have made various attempts in formulating and categorizing these functions of the innovation system, including methods of analysis to assess the fulfillment of the individual functions. For this research we use the function set from Hekkert et al. (2007), since this set was derived from comparing and combining many empirical studies on innovation systems and is therefore thoroughly grounded in empirical data. An overview of the functions, including potential barriers, is provided here:

- *Entrepreneurial activity*

  Within innovation systems there is a great uncertainty about which technologies work and which fail. Entrepreneurs have an important task in experimenting with these new technologies and applications, since they are more inclined to take the enormous risks that are associated with these experiments. Therefore entrepreneurs are usually also the first ones that take concrete actions. By using the newly created knowledge, market and networks they take advantage of new business opportunities and they are able to learn a great deal about the technology in practice, consumers, suppliers and competitors. Because of these experiments and advanced learning, entrepreneurs are especially important in the early stages of an innovation system. They help to shape the first system contours and can provide guidance for the search of other actors for a viable implementation of the technology. Entrepreneurs can either be new firm entrants or existing firms that diversify their activities towards the new technology. A lack of entrepreneurial activity can seriously hamper the development of an innovation system, because the uncertainty on the viability of the technologies remains too high, mostly due to a lack of learning-by-doing and practical knowledge.

- *Knowledge development*

  The development of knowledge within the innovation system is an important process within each innovation system. There are different types of knowledge that can be distinguished, such as scientific, technological, market, etc. It is important for the innovation system that the right type of knowledge is developed in the right stage of the innovation system. In the beginning the focus can be on more fundamental research, but later on this should shift to more applied and practical knowledge. A lack of knowledge development can hamper the innovation system because when technological breakthroughs and improvements hold off, the chances for a successful implementation of that technology are reduced.

- *Knowledge diffusion through networks*

  In order for knowledge and information to be used efficiently it needs to spread to and from the various actors in order to be commercialized and applied in the right places. Using the actor network in the innovation system the knowledge can reach the relevant actors. This can happen through joint projects, workshops and other forms of collaboration. The diffusion of knowledge and information is important in a closed R&D setting, but even more so in a heterogenic environment in which regulations, standards and policies are being developed and need to be matched with each other. In case the diffusion of knowledge falls behind valuable knowledge might not reach the right actors, which in turn can slow down the technological development. In addition a lack of interactions and exchange of information between system actors can also lead to mismatches between the technology and the regulations, technological standards and expectations.

- *Guidance of the search*
  Influence on the guidance of the search can be seen as a guiding mechanism for the selection of knowledge and technologies that was developed in the previous functions. Because resources are limited and can often only be employed once, it is important for system actors to have sufficient guidance to help them in their investment decisions for those resources. The influence on the direction of the search exists both outside and inside the innovation system. Outside influence can motivate firms and entrepreneurs to engage within the innovation system. Influence on the search within the innovation system can provide more security with regard to the dominant technology, markets, applications and societal acceptance. If there is not enough guidance of the search, investors and other actors might refrain from making investment decisions for their resources, slowing the overall development of the innovation system.

- *Market formation*
  The market formation function is about creating a new market for the newly developed technology. Since newly developed technologies can be rather 'crude' and inefficient in the beginning, they often still carry several disadvantages in comparison with the reference technology. In order to allow the technology to be commercialized and to buy some time to further refine the technology, it is useful to create a niche market. This might either be done by providing favorable regulatory conditions for the new technology or by looking for a (temporary) specialized market, in which the new technology can already compete with the reference technology. Without a (niche) market for the new technology it will be difficult for the technology to exit the incubator phase of development, because it is not possible to show its application to a larger audience and to learn from the practical application of the technology.

- *Legitimacy*
  Legitimacy concerns the social acceptance of a technology and influences the ease with which resources are acquired and new (research) projects are approved. Gaining sufficient legitimacy is also crucial in tipping the scales in favor of the new technology and innovation system, thereby efficiently destroying the old system. Often actors with vested interest in (older) competing technologies will try to counteract the development of the new technology. Sufficient legitimacy is then required to oppose these destructive forces. Legitimacy for the new technology can be build by creating advocacy lobbies that in turn can plead for resources or for more favorable regulatory regimes. If legitimacy lags behind it may hamper the market introduction of a technology, reduce the amount of political support and limit the amount of available resources.

- *Resource mobilization*
  This function describes the availability of resources in the innovation system. Examples of these resources are financial resources, human resources and complementary assets (infrastructure, services, etc). These resources form an important input for the innovation system as all the previous functions require some kind of resources to be able to function properly. A scarcity of resources of this kind can therefore seriously hamper the other functions and therefore also the development of the innovation system.

Since an innovation systems is not a steady state system, it changes dynamically over time. This happens due to interactions and influences between the system functions and between the components and the functions. A lack of legitimacy might result in a lack of available financial resources, which in turn can cause research projects to be put to halt, thereby hampering knowledge development. Of course these kind of inter-functional interactions can also work positively. A strong diffusion of knowledge can grow awareness and legitimacy for a technology which then can motivate entrepreneurs and firms to start experiment with the technology. The functions can thus either weaken or strengthen each other. Within these kind of mechanisms barriers might also reside and will therefore also need to be studied in this research to provide a complete picture.

3. Method

In this research we will use a case study analysis with an embedded single-case design, which implies that in studying the whole technological innovation system (our main unit of analysis) we also look at subunits, such as the system components, the system functions, interactions, individual actors, projects, relations between actors and clusters of actors. It is important to study these subunits as well, since our theoretical framework has been developed with the assumption that potential barriers for the transition to an active distribution network must reside within the structural components, the system functions or within the interactions between them. Therefore it is important to submit these system functions and components and their underlying units to a systematical analysis. To do this we shall partly adopt the scheme of analysis developed by Bergek et al. (2008). This scheme of analysis deals with both the three structural components as well as the system dynamics of a technological innovation system. It begins by choosing the unit of analysis. This means that the exact innovation system, thus the main unit of analysis, has to be delineated. The following step is to analyze the components of the innovation system, i.e. actors, networks and institutions, and to analyze the system functions. The next step is to identify the interactions between the structural components and the system functions and then we will be able to draw conclusions about the barriers to the transition to an active distribution network.

3.1 Operationalisation

According to Carlsson et al. (2002) a technological innovation system can be analyzed on different demarcation levels. One of the levels he identified is the *competence bloc*, which he defines as *"a set of related products […] aimed at satisfying a particular function"*. This fits well with active distribution networks, since the focus will not be on a specific technological component, but more on the type of application or function of a set of technologies. Making the transition to an active distribution network requires a broad range of technologies, both from the field of electrical engineering and from the ICT sector. Therefore all technology that helps create the function of an active distribution management (in accordance with the definition by Liew et al.), will fall within the boundaries of our innovation system. The spatial focus will be on the Netherlands, but we will also examine European influences on the Dutch developments since we cannot ignore those entirely. The European Union has large ambitions when it comes to the modernization of the electricity grid. Recently they called smart grids "*a key enabler for a future low-carbon electricity system*" (EC, 2011). Because of this European focus on smart grids the European Union supports a lot of pan European research efforts and, in addition, intends to stimulate the development of smart grids[3] in European Member States. European research efforts might be important for the transition to active distribution networks in the Netherlands and also future national policies, laws and regulations might be revised under the influence of the EU. To illustrate this with an example, the European Union has already requested that their member states come up with action plans and targets for smart grid development and has announced to come with a mandate that will force Member States to do so if the progress of implementation lacks behind. The spatial focus will therefore be primarily on the Netherlands, but where relevant, we will account for European influences by including them in our analysis as external one-directional influences on our innovation system.

Now that the technological innovation system is delineated we will need to identify the structural components of the innovation system and analyze them for barriers. For the *actors* and *networks* components this means we will resort to a social network analysis, as was explained in the theory section. This analysis allows us to graphically map all relevant actors and their reciprocal relationships and, using statistical measures, it enables us to make statements about the network and actor characteristics. A social network analysis can be used to analyze the network as a whole or it can be used to analyze single actors within the network. For this research we will do both as barriers to innovation can be found in both the overall structure of the network as well as in the network position of individual actors. Although

[3] The EC refers to smart grids when it comes to grid modernization, which among other things, includes active distribution networks.

the primary focus will be on the Dutch network which lies within the boundaries of our technological innovation system, we will also do a network analysis including both Dutch and European projects. This enables us to analyze the links between the Netherlands and Europe and can teach us more about the before mentioned influences from European developments.

The social network analysis will be done using the software program Pajek, which is used to prepare the data, and using the program Visone, which can do the actual analysis. For the analysis of this network we will use several statistical measures that describe characteristics of the network. The network as a whole can be analyzed, according to two dimensions (van Alphen et al., 2010), network size and network connectivity. Network size is determined by two measures: the number of actors and the average distance between actors in the network. The latter measure will mainly determine the density or sparseness of the network. The more dense the network, the less the average distance between network actors will be. The network connectivity is determined by *mean degree* and the *network clustering coefficient*. The mean degree is the average of all connections for each actor and thus determines the average number of relations each actor has. The higher this number, the more intense the cooperation is within the network. The network clustering coefficient is the average of all individual clustering coefficients. The higher this number, the more clustered the network is. A lower number can indicate a fragmented network. By analyzing these network measures the structure of the network can be determined. As Kim (2009) already pointed out, a small-world network is the best structure to foster innovation. Small-world networks are densely organized and are highly clustered, meaning that they have a small *average distance* and a high average *clustering coefficient* (Watts, 1998)

We will also analyze individual actors. This will be done using the measures *closeness*, *degree*, *betweenness* and *clustering coefficient.* The *closeness* measure can tell whether the actor is positioned in the periphery or the center of the network. It is calculated by taking the average distance to each actor in the network. The more central an actor is, the lower that average distance will be. The *degree* measure is defined by the number of connections an actor has within the network. This represents the number of firms an actor is connected with. The more connections a firm has, the more and diverse knowledge and information can flow through and from that actor. *Betweenness* is a measure that defines the importance of an actor to connect different parts of the network. Depending on the shape of the network, thus whether the network is very dense or very sparse, this measure gets more meaning. In a very dense network the betweenness will likely not differ a lot among actors, as all actors are connected with each other through many different paths. In a very sparse network, though, a single firm might be the only actor connecting different clusters in the network, which means that firm will get a very high betweenness in comparison with the other network actors. *Clustering coefficient* measures the connectivity between neighboring actors. When Firm A is connected with three other firms and these three firms are in turn also connected with each other, actor A will get a clustering coefficient of 1. Actors that have a low clustering coefficient are connected with actors that are not connected with each other.

The first three measures *degree, betweenness* and *closeness* are often grouped together in the literature as an indicator for the *centrality* of an actor. The *centrality* of an actor can indicate the importance of that actor in the network (Freeman, 1979). The type of actors that are central and active or not central and active in the network can provide information about the system functions. E.g. if the centre of the network consists mostly of research institutes this can mean something for the *knowledge development* function and when project developers are missing in the network this can mean that the technology is not commercially attractive yet and that the *market formation* function is still lagging behind. The measures *betweenness* and *clustering coefficient* are both able to indicate actors in the network that form a hub to connect different parts of the network. A low clustering coefficient and a high betweenness for an actor indicate such a hub. These hubs are likely to be better aware of what is happening within the innovation system and are important in facilitating the diffusion of knowledge and information through the network.

The third innovation system component, the institutions, is shaped by the laws, regulations, policies and normative structures that are in effect. We will describe these institutional factors, so that barriers that negatively influence the system functions can be identified. One example, that already showed up in the introduction and that partly led to this research, is the regulatory framework in the Netherlands. According to the literature this regulatory framework prevents the DSOs from investing in network innovations. This is an example of where the institutions, as a structural component, negatively influence the *resource mobilization* function.

After operationalising the structure of the technological innovation system the system functions can be examined. For each of the seven system functions a comprehensive narrative will be constructed on the basis of what has happened and is happening within the innovation system. This will mostly be done on the basis of the projects and actors that are active in the active distribution network. For example, when a pilot project is launched that (1) explores an active distribution network application, (2) is funded by venture capital and (3) is in cooperation with a university, this project can provide information on the functions (1) *entrepreneurial activities,* (2) *resource mobilization* and (3) *knowledge development and diffusion.* Also certain events or documents related to active distribution networks can provide information on the functions. Events, such as the grant of subsidies, can help to give insight in the *mobilization of resources.* Availability of subsidies can mean there is no shortage of resources and thus no barrier. And official documents, for example released by the government or industry associations, can help to analyze the different visions shared by important actors in the innovation system. This in turn allows us to analyze whether there is enough guidance of the search within the innovation system. Very different visions could mean there is no proper guidance, which could be a barrier to the transition to active distribution networks.

Finally, after drafting a thorough description of the innovation system, its structural components and the system functions we will search for influences and interactions between them. As explained an innovation system is not a static entity, but rather a dynamically progressing system that grows, evolves and changes over time. The dynamics are interactions and influences between the structural components and the system functions and are very important for the development of the innovation system. It will be useful to know if a certain function is not performing well, but it will be even more useful if we know why that function is not performing well, in other words, by what other function or structural component it is negatively influenced. Since we have not done a historical analysis of the innovation system we have no real empirical data to use for the analysis of the interactions. Instead we will heuristically analyze the results from the structural components and the functions of the innovation system. To distinguish between the empirical results for the structural components and the system functions and the heuristically analyzed interactions, they will be split out in two different sections.

3.2 Data collection and analysis

Our case study will be built on three sources of data. First we have constructed a database that includes all active distribution network related projects and the involved actors. This database will allow us to construct the network and to calculate the earlier described statistical measures. A project is included in the database when it incorporates the 'active' component, thus it should contain the real-time management (on site or through communication systems) of voltage, power flows, fault levels, etc. between the network operator and the control devices (Liew, 2002). Also projects incorporated in this analysis will need to be done by two or more partners. This is because the network analysis is used to focus on the interaction between different actors in the innovation system (enabling diffusion of innovation). Actors are connected with each other, i.e. a tie is formed between them, when they work together in the same project. We will also incorporate European projects and actors in the database, but this will solely be to analyze the link between the Netherlands and the developments in Europe. The information about the relevant projects is gathered by using (1) the Dutch governmental website on smart grids that keeps track of all smart grid related projects, (2) the European database CORDIS wherein all European research projects are documented, (3) by using a research effort from the Joint Research Centre of the EU that aims to catalogue all smart grid projects (JRC, 2011) and (4) by searching the internet for any other relevant projects, both on the national and the EU level. This search has led to a total number of 47 relevant projects in which 279 actors are involved. Second, available literature on active distribution networks is studied and used to see whether there is any relevant information on the system components and functions. This includes scientific literature, but also relevant documents, papers and articles published by actors in the innovation system or other (international) actors that are related to active distribution networks. And finally, four interviews will be conducted with experts in the field to validate the findings from the first two sources of data and to add any other missing information about the system functions and components. The interviewees are selected on the basis of their experience and history in distribution networks. The interview questions are roughly based on the set of indicative questions as listed by van Alphen et al. (2010), but are adapted according to our findings on active distribution networks from the other two data sources. The interviewees (including their experience and background) and the interview questions can be found in appendix A.

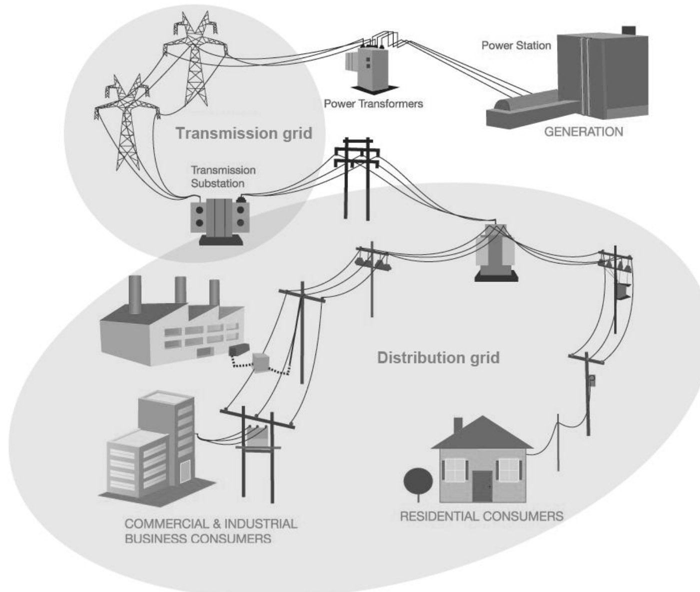

Fig. 4: *Schematic overview of the electricity value chain*

4. Results

This section will present the results from the analysis of the technological innovation system. To begin with a general overview of the innovation system is presented to make the reader familiar with some of the important actors and institutions. After that the structural components of the innovation system are further explained, which also includes the social network analysis. Subsequently the system dynamics, thus the seven system functions, are examined.

4.1 Overview of the innovation system

The electricity system in the Netherlands can roughly be divided in three voltage categories, the low voltage, the medium voltage and high voltage electricity lines. The high voltage lines, or the transmission grid, are operated and maintained by the transmission system operator TenneT and the medium and low voltage lines (the distribution grid) are maintained and operated by eight Dutch DSOs (fig. 4). The transition to active distribution networks affects only those medium and low voltage networks[4] and therefore the distribution system operators are important actors for the transition to active distribution networks. In the Netherlands the DSOs are unbundled from the retailers and generators in accordance with European legislations and therefore have to be independent firms. The three DSOs in the Netherlands that are responsible for the lion's share of the distribution networks are Alliander, Enexis and Stedin. Besides these three, there are five other DSOs active in the Netherlands that cover marginal areas. The DSOs are private firms that are owned by municipalities and provinces and are regulated by the Office of Energy Regulation, which in turn is part of the Dutch competition authority. The Office of Energy Regulation formulates regulations and sees to it that these are complied with. The regulations are specific implementations of legislation from the Dutch ministry of economic affairs. The DSOs are organized together in the industry association of Netbeheer Nederland, which published a roadmap on smart grids in September 2010. In this roadmap they identified pressing issues that needed to be resolved in order to modernize the distribution grid in a smart way.

The DSOs are, however, not the only actors involved in the transition to active distribution networks. A study from Ecofys (2011) shows that so far roughly a quarter of the actors involved in transition to active distribution networks are energy related actors, thus actors that are part of the electricity value chain. Another quarter consists of research institutes and universities and yet another quarter is formed by 'supportive'

[4] The (high voltage) transmission grid is also subject to modernization efforts, but those falls outside of the scope of this research.

companies, such as technology suppliers and consultancy firms. The remaining actor base consists of governmental actors, such as provinces and municipalities, and some unions and associations. Even though this is just a rough estimation, it does provide some idea on the type of actors that are currently involved in the transition.

The Dutch government is also preoccupied with the transition to active distribution networks and has acknowledged its necessity in the recent 2011 energy report. Earlier, in 2009, the Dutch ministry of economic affairs installed the Taskforce 'smart grids' to support the modernization of the distribution grid. This Taskforce had to come up with a broadly shared vision and an action plan for the future of smart grids in the Netherlands. In 2010 they presented a discussion document, which, after discussions with relevant actors, led to final document in 2011. Following the recommendations from this document the government opened the IPIN Scheme in June 2011. This scheme is managed by the Dutch agency AgentschapNL, which has a supportive and executive role for the ministry of economical affairs and coordinates the governmental efforts in stimulating the modernization of the electricity grid. The innovation scheme has 16 million euro available to support pilot and demonstration projects.

4.1.1 The structural components: actors and networks

The total network of actors, spanning both the Netherlands and the European playing field, consists of 279 actors that cooperate with each other through 47 different projects. From these projects 21 were Dutch, i.e. they were based in the Netherlands, Dutch firms were involved and they were funded by Dutch financial sources (such as the IOP EMVT[5] program and the Energy Research Subsidy (EOS) program). The other 26 projects were European based. These projects are mainly funded by the 5th, 6th & 7th Framework Programme[6] and the Intelligent Energy Europe (IEE) program. From the 279 actors that we included in the network 37 were from Dutch origin and 242 were based abroad. In Appendix B we have included a set of tables and two figures that show these numbers in more detail. Also the results from the statistical analysis, on which we will further elucidate in this section, are provided there in more detail.

From the analysis of the network we have found that on average it takes about 2.14 actors to reach any other actor in the network and that each actor has an average of 31 connections. The average clustering coefficient is 0.87. Since a clustering coefficient of 1 would imply that the network consists of one dense cluster, this means that the network as a whole is rather interconnected and does not hold separate and isolated clusters. Looking at these numbers from the analysis we can conclude that the actor network is rather dense. With a low average distance and a clustering coefficient near to 1 this network resembles a small-world network. According to Kim (2009) this type of network layout is especially suitable to stimulate innovation. Actors are closely interconnected, meaning that they are likely to be able to get in touch with each other and that information and knowledge can spread easily and quickly. Actors are also likely to be well aware of which other actors are active within the network and what projects are being done.

Besides the overall network characteristics we have also examined the relationship between the Dutch and European projects and actors to learn more about the influences and interactions between the Netherlands and the European Union. By looking at the individual clustering coefficients and betweenness values we are able to make a statement on the interrelatedness. In case there are strong connections between the Netherlands and the European Union we do not expect to find individual Dutch actors that show very noticeable values for betweenness and the clustering coefficient, as those would suggest the existence of separate clusters in the network. But if the interrelatedness is low and the Dutch and European projects are only linked by a small number of firms, these firms should stand out with their values for the betweenness and clustering coefficient. The three Dutch firms that score the highest for betweenness and the lowest for the clustering coefficient are Energieonderzoek Centrum Nederland (ECN), Kema and Alliander. In examining these actors closer we indeed find that ECN is involved in 15 Dutch projects and 11 European projects, that Kema is active in 11 Dutch projects and 4 European projects and that Alliander can be linked to 12 Dutch projects and 3 European projects. No other significant actors can be found that play a role

[5] IOP EMVT is a Dutch innovation-driven research program for electromagnetic power technology.
[6] European Framework programs for research and technological development

in bridging the European Union and the Dutch innovation system. This means that from the 37 Dutch firms that are active in the innovation system only three are also involved in European projects. The interrelatedness between the Dutch and European actors is thus rather low, which was also confirmed by an advisor of the Dutch innovation program for smart grids we have interviewed.

Since the transition to active distribution networks is a transition that requires a lot of different actors from different disciplines to cooperate with each other we have also looked at the heterogeneity of the actors in the network. In the general overview of the innovation system we already found that the current mix of actors mainly exists of electrical utilities (DSOs, generators, retailers), research institutes, engineering and consultancy firms, ICT related firms and municipalities and provinces. One type of actor that is lacking, according to one of the interviewees, are contractors, which are in the end responsible for building part of the infrastructure. In analyzing the network according to the individual actor characteristics we find that the actors that rank the highest for the three centrality measures in the Netherlands are ECN[7], Kema and Alliander (see table 1). These firms have the most connections with other actors, are important in connecting other actors with each other and are located in the centre of the network. It is noticeable that these same actors were also found to form the link between the Netherlands and Europe. Using the network analysis it is unfortunately not possible to say whether involvement in Europe led to a key position in the Dutch innovation system for these actors or whether it was the other way around, but it seems likely that this mechanism has worked in both directions.

Actor	*closeness*	*degree*	*betweenness*	*clustering coefficient*
ECN	0.00238	139	6418.651	0.206
Kema	0.00204	65	2497.404	0.244
Alliander	0.00200	61	2683.898	0.340
APX-ENDEX	0.00188	41	94.760	0.805
TenneT	0.00182	30	92.385	0.729

Table 1: *the top 5 Dutch actors, ranked by their closeness*

Our results also draw attention to the role the Dutch DSOs play in the transition. Since DSOs are ultimately responsible for operating the distribution network we would expect that they play a major role in the innovation system. Their importance is also suggested in a recent study by the Joint Research Centre (2011), which did a study on European smart grid projects and confirmed "*[…] the leading role that Distribution System Operators (DSOs) play in coordinating Smart Grid deployment across Europe*". When we look at the centrality measures of the three largest Dutch DSOs we see that Alliander scores high and ends in the top three of the most central network actors. Enexis and Stedin, on the contrary, score noticeably lower and are not involved in European projects. When asked, however, Enexis and Stedin attribute these differences to a different style of communicating projects and also mention the differences in absolute size (number of clients served). When asked about their role in the transition to active distribution networks the interviewees from the three largest DSOs do not confirm that DSOs should have a leading role in the transition. Instead they stress the importance of the consumers and generators as a starting point for active distribution networks. These different opinions about the role of DSOs appear to be part of a more comprehensive problem of uncertainty about the role of many individual actors in the innovation system. This issue is elaborated further upon in the section about the *guidance of the search* function.

4.1.2 Structural components: Institutions

The institutions are the laws, regulations, policies and normative structures that guide and limit the actors in their behavior. These factors play an important role in this case, since distribution networks, as a natural monopoly and as a vital service in our society, are subject to a lot of laws and regulation. This means that a transition to active distribution grids is also affected by these laws, policies and regulations. The law, for example, prohibits the DSOs to discriminate in connecting generators or consumers and obliges the DSOs to always be able to supply peak demand[8]. The regulations prescribe the tariff structures, the rate of efficiency improvement and some other things to ensure that the tariffs for the distribution grids remain

[7] As of the 12th of April all the electricity grid related activities of ECN will be transferred to the Dutch Institute for Applied Scientific Research (TNO).

[8] Dutch Electricity law, article 16, paragraph d.

reasonable. Since also the type of network investments (both short term and long term and innovative and non innovative investments) depend on the regulatory framework it is obvious that the regulatory framework has an impact on the way the DSOs deal with these investments. Policies provide guidance with regard to the future of the energy system and therefore also affect the transition to active distribution networks. These influences and mechanisms make that the laws, regulations and policies are part of the institutional environment. We will therefore elaborate further on these in this section.

Recently the regulations have come under attack because they would be focused too much at reducing short term costs and would limit the possibility for DSOs to invest in network innovations. Eurelectric, the pan-European association for the electricity sectors, has recently released a report on the regulatory problems in the EU member states. Among other things they found that investments in grid modernization are hampered because of sub-optimal rates of return and regulatory instability and that regulators are taking a narrow view in evaluating the effects of network investments (Eurelectric, 2011). This is backed up by the paper of Niesten (2010), which states that the regulatory framework in the Netherlands fails to properly stimulate the network investments that are needed for network innovation. Both the Eurelectric report as well as the paper by Niesten (2010) identify several structural regulatory barriers in the Netherlands that hamper long term network investments. The first barrier is that the tariff that is charged for a specific network service has to be directly related to the costs for that service. Also costs may not vary too much from one year to another. These requirements make it hard to get a fair rate of return for long term investments. A second, more politically oriented, barrier is that there is always the risk that a political decision is made to limit the tariff at a certain level, thereby preventing the DSO from earning back their investment. Because the regulatory period varies from 3 to 5 years in the Netherlands and because the investments done by a DSO are often done for periods of 10 up till 50 years long term innovation is a risky activity for DSOs. A change in regulations could easily jeopardize the profitability of network innovations. A third regulatory barrier, according to Meulmeester (2008), is the yardstick model that is used in the Netherlands. This means that the regulator will set the tariff based on the average costs of the DSOs. If one DSO decides to invest it will have relatively higher costs than the DSOs that do not invest. Because the tariff is set based on the average costs they will have a more difficult time earning back their investments with the low tariff. The DSOs are thus incentivized to postpone network investments.

Besides these regulatory issues, there are also some barriers in the law that makes it difficult to earn back investments in network innovations. DSOs are obliged to always deliver the demand that is required by the clients on the grid, thus any innovative projects that aims at peak shaving cannot replace the costs for traditional network reinforcements, but will always come on top of these costs for reinforcements. Also their obligation to connect any generator to the grid without being able to charge this generator extra costs for the connection, limits the amount of financial resources that are left to invest in active distribution networks. These law and regulatory issues limit the ease at which system actors can engage in innovative projects. The interviewees acknowledge these issues but stress the importance of experimenting with the technology and applications first. The experience and lessons learned from these experiments could in the future show where and how regulations and laws have to be changed. A recent study from the Dutch agency AgentschapNL (2011) points out that small scale innovative pilot and demonstration projects have the option to be exempted from the law. This was defined in the 'Crisis and Herstel' law. On the other hand the study also confirms that the current laws and regulations are outdated and would not allow many of the applications of an active distribution network. This implies that when the time is there for large scale applications of active distribution networks these laws and regulations should be changed accordingly.

The energy policy of the Dutch government is also likely to influence the transition. At this moment clear policy for the future energy system is lacking in the Netherlands. In the 2008 energy report the government stated that they would refrain from using any blueprint for the energy system in 2050. Instead the Dutch government aims to let the market select the energy technologies of the future. This market approach is also reflected in the recent 2011 energy report, where the government stresses that every investment in renewable energy sources should generate new jobs and economic growth. According to multiple interviewees this passive attitude of the government towards future energy and grid technologies, slows down the progress of the transition, since there is little attention for small scale renewable energy sources. The failure of Dutch policy to properly stimulate renewable energy technologies has already been shown in several other studies such as Suurs (2005), Klomp (2004), Negro (2007) and Negro (2009). Because the development and implementation of small scale renewable energy sources (such as solar panels and wind mills) lags behind, there is a no strong incentive to start transforming the electricity network. And without the transformation of the electricity grid promising prospects for energy savings and CO2 reductions are put to waste. The Dutch energy policy is in sharp contrast with, for example, a country like Germany, where they have launched the '*E-Energy Program*' that aims to "*[…] create a smart electricity system, which will extensively control itself and in which all energy-sector processes are optimally adapted to one another*". This aim is also expressed in the National Electromobility Development Plan, where the German government states: "*The efficiency of power grids in Germany is to be enhanced through the use of modern information technologies and the integration of electric vehicles*". Together with their successful policies on stimulating PV cells and bio-fuels the German government pursues a more proactive policy.

In addition to the national government the European union also has quite some institutional influences. After identifying smart grids in 2004 as an important prerequisite for the desired low carbon future, the EU decided to establish a European Technology Platform (ETP) dedicated to smart grids. The aim of the platform was to formulate a vision for the development of the European electricity networks towards 2020. Together with this vision they also published a strategic research agenda which identified important smart grid research subjects. Based upon these recommendations there have been a lot of research programs that were funded under the 7th Framework program, the Strategic Energy Technology (SET) plan and the Intelligent Energy Europe program. The SET plan was created to compensate for the lack of energy research funding in the 7th FP. After finishing the vision, research strategy and strategic deployment document the platform was turned into a forum whose main role it will be to accompany the deployment of the developed strategy.

In order to advise the European Commission on regulations related to smart grids the 'Smart Grids taskforce' was established. Using the feedback generated from the many research projects, the ETP forum and the European Electricity Grid Initiative, the task force helps the EC to develop new directives or provisions that need to encourage member states to develop (regulations on) smart grids. As of June 2010 the Commission issued a mandate to European standardization organizations to develop standards for smart meters. Later, in march 2011 they issued the same mandate for smart grid standards. The third energy package, a collection of revised energy directives, obliges member states to investigate the roll out of smart meters and demands that 80% of the positively assessed meters will be rolled out by 2020 (EC, 2009). Extending beyond the scope of the third energy package, the EC has also requested member states to produce action plans with targets for the implementation of smart grids. Depending on the progress of smart grid deployment in member states the European commission might also develop regulatory incentives to further stimulate smart grids. This will either be done by revising the energy services directive, part of the third energy package, or by the development of network codes (EC COM 112/4, 2011).

4.2 The system functions

4.2.1 Entrepreneurial activity

Entrepreneurial activities are essential in learning about how technology works in practice. It helps to learn about the interaction between consumers and the technology, it can point out which technological configurations are optimal and it enables to provide guidance for future projects (Hekkert, 2007). In the Netherlands there have been several pilot projects so far which were mostly focused on testing technological solutions. At this moment there is only one pilot project that demonstrates the actual operation of an active distribution network. This project, called PowerMatching City, consists of 25 households which are connected with each other through the PowerMatcher system. This system allows to balance supply and demand on the local grid by incorporating generators, such as windmills and micro CHP units, and by including household appliances for demand-response services, such as heat pumps and washing machines. Other demonstration projects are 'Smart Storage pilot', where the impact of a flexible energy storage unit in the distribution network is investigated and the 'micro CHP virtual power plant' project where a cluster of micro CHPs aggregated together into a virtual power plant is tested. These latter two projects, however, have only been operating in an isolated test setting. So far the focus of demonstration and pilot projects has primarily been on the hardware side of active distribution networks. Projects focusing on the softer side of active distribution networks, thus the social and economical aspects, are still lacking. The interviewees have confirmed this and have stressed the need for more pilot projects that help explore those softer aspects of active distribution networks. Especially the uncertainty about how consumers will respond to an active distribution network and whether they will be willing or able to change the way they use energy remains an open question. This scarcity of pilot projects of this kind was also identified by the taskforce 'intelligente netten', whose main recommendation to the government was to provide funding to stimulate the start up of more pilot projects focusing on the soft aspects of active distribution networks. This recommendation was picked up by the government, who made 16 million euro's available for the development of pilot projects under the IPIN[9] scheme.

4.2.2 Knowledge development

In the Netherlands there is a large number of research institutes involved in active distribution network related projects. Institutions like (technical) universities, ECN and also commercial consultants like Kema, have been involved in a number of projects that were aimed at technological and fundamental research. Almost all of these projects were funded by the EOS program (Energy Research Subsidy). Examples of such projects are DEVS, where the impact of distributed generation on the voltage levels is investigated and FLEXIBEL where a system was developed to more easily integrate distributed generation. But it seems it is time to shift from a technological focus of knowledge development to a more social and economical focus. While all the technological solutions are already developed or can be developed, there is great uncertainty about how customers will react to an active distribution network, about which actors are going to play which role and about where the costs and benefits are going to land. This latter issue mainly results from the recent unbundling of the electricity supply chain. Investments in the distribution grid that lead to a more balanced demand and supply and energy savings might benefit the consumers and retailers of electricity, while the distribution system operator cannot earn those investments back. These kind of issues need to be resolved to allow all the actors to get a fair rate of return on their investments. The Dutch Taskforce 'Intelligente Netten' also confirms that all the necessary technological knowledge has been developed and is available. Instead they stress the need to find a workable business model and to include the end-users (households, industrial users and generators). As a result of these conclusion by the taskforce the recently launched IPIN scheme demands that participating projects should not focus on technological development, but instead focus on learning about these social economical issues. The interviewees also agreed with this point of view and stress the need to find out how consumers respond to different implementations of the active distribution grid and the need to find out which role each actor will play in an active distribution network. The Dutch DSO Enexis is currently working on a pilot in Breda where the main goal will be to find out more about the behavior of the consumers. According to their opinion they "*first have to find out what is going to work and what consumers want, before we can start to invest in the network and transform the distribution network*". This point of view is also shared by the Dutch DSO Stedin which states that "*there are so far not enough projects that include the end-user*", but also confirms that "*there is a growing awareness that the end-user is the most important link*".

The need for the development of more social and economical knowledge is thus acknowledged within the system. Part of this knowledge might be found in European projects, which are in general a little ahead of Dutch projects in terms of scale. But as the analysis of the next system function (diffusion of knowledge through networks) will show there is little interaction with European actors and projects.

[9] InnovatieProgramma Intelligente Netten

4.2.3 Knowledge diffusion through networks

From what we can see in the social network analysis the actor network is very densely organized. This suggests that the various actors are closely connected and that knowledge and information is likely to spread easily through the network. Also there have been many efforts to bring actors together. First the government initiated the conference 'Towards Smart Grids'[10] where relevant actors could provide input for the vision document that was to be released by the ministry of economic affairs. During this conference various workshops were organized in which actors could discuss a wide range of active distribution network related topics with each other. Another initiative, which came from the industry association for Dutch DSOs, was the installation of a project group for smart grids. They were to draft a roadmap for smart grids and to organize three interactive sessions during which all actors could exchange information with each other. A third example is the Smart Energy Collective, which was initiated by Kema. This collective was created to share knowledge and information amongst the participants and to jointly come up with a large scale pilot project. And also informal initiatives were launched. The consultancy- and engineering firm Movares, for example, used the social media website Linkedin to bring together interested actors and organized an open brainstorm meeting. That these kind of meetings and conferences are widespread is confirmed by the interviewees. One of them even pointed out that "*if she wanted to she could go to a meeting every day*". In addition the interviewees all claim to be well aware of the network, the actors and the projects that take place. The importance for all these actors to collaborate with each other and to exchange knowledge and information is also stressed in several documents. A recent publication by the Low Carbon Network Fund (LCNF), which is aimed at preparing the distribution network for a low carbon future, acknowledges the importance of inter-firm and inter-institutional collaboration and knowledge sharing: "*We expect DSOs to collaborate with each other and non-DSO parties (External Collaborators) on many of the projects supported by the LCN Fund. DSOs are likely to have to work closely with other parties in the electricity supply chain (from generators to suppliers) to explore what technology or commercial arrangements best address changes in network use and what role they can play in facilitating low carbon and energy saving initiatives such as demand side management and DG*" (OFGEM, 2010). The importance of collaboration and interaction for the transition to active distribution networks is also backed by academic literature. Keller and Wild (2004) state that long-term investments in distribution grid innovations, due to problems as transaction costs and imperfect information, are better done using coordinating groups of all parties involved.

On the contrary, when we look to the exchange of knowledge and information with European actors and projects, we can see a different picture. In analyzing the actor network we already found that the connections between Dutch actors and European actors and projects are rather limited and that the two or three actors that do bridge the Dutch innovation system with Europe are also the most central actors in the innovation system. This suggests that there is some kind of advantage to get involved in Europe and draw from knowledge and information there. This conclusion is backed up by the advisor of AgentschapNL, who states that Dutch actors should make more use of the knowledge and experience developed in the European projects. A specialist in innovation from the Dutch DSO Enexis acknowledges that they are not very actively involved in European efforts, but seems to disagree on the necessity of that involvement. According to him the local circumstances in which Enexis has to work on active distribution networks differ to much from the European perspective. But when we analyze the European actor database we find that there are many foreign DSOs that take a central position in the European part of the network. It thus remains rather ambiguous so far whether close interactions and cooperation with European projects could actually spur the development of the Dutch innovation system, but the weak connection between the Dutch actors and European actors at least shows that the diffusion of knowledge and information between Europe and the Netherlands has so far been rather limited.

4.2.4 Guidance of the search

For each innovation system it is important that the actors have some kind of idea or expectations in which direction the innovation system is moving. This will help actors in their investment decisions and can also help creating more legitimacy for the technology. Since the transition

[10] ' Op weg naar Intelligente Netten'

to active distribution networks is a transition that requires investments in many different parts of the infrastructure (of which some cover a period of up to 50 years) and requires the involvement and cooperation of a large amount of end users, a clear and strong guidance of search will be important.

In reviewing the current projects related to active distribution networks we find that there is large variety of content. The projects differ in their societal and technological aims, make use of different technological solutions and vary in size, comprehensiveness and approach. Enexis illustrates this by distinguishing two different approaches for active distribution networks. First, the technological approach, where the desired flexibility in the grid is mostly realized using technological solutions, such as storage units and controlled demand response. And second, the market approach, where the flexibility is achieved by fluctuating the prices and by letting end-users trade electricity with each other. When looking at the current project portfolio the focus has so far mostly been on the technological approach. The most obvious explanation for this is that the market approach conflicts more with the current laws and regulations than a technical approach would do, since the pricing mechanism and tariffs are heavily regulated. Enexis believes that both approaches will be important for the future of the distribution grid, but also acknowledges the uncertainty that exists with other actors about what approach to take. Another factor of uncertainty is the scale at which the distribution network has to be smartened. In the discussion document by the Dutch taskforce 'Intelligente Netten' three future scenario's are sketched. The first scenario, *powerhouse*, envisions the exchange of electricity between European member states to cope with the fluctuations in electricity production. The second scenario, *Flexwerker,* aims to smarten the electricity grid at the MV level to provide more flexibility in the electricity supply. The third scenario, *smart energy city*, envisions the actual participation of households and the large scale integration of small generators.

It is mainly this kind of different perceptions of future socio-technological scenario's that lead to confusion and uncertainty about how the transition will proceed. This uncertainty is strikingly illustrated by the following example: In October 2009, the Dutch government installed the Taskforce 'Smart grids' to develop a vision document for the electricity grid of the future. Instead of developing a vision the taskforce came up with the discussion document that sketched the few future scenario's. The taskforce had to conclude that there was a lack of knowledge and experience to sketch a clear vision and advised to do more pilot and demonstration projects to reduce the uncertainty. The interviewees confirmed the important role of these pilot projects in providing guidance of the search, but also mentioned the lack of policy by the government as a limiting factor for this system function.

4.2.5 Market formation

There are currently little or no products or solutions commercially available on the market for the active distribution networks and we can therefore state that the market formation has hardly started yet. This is also confirmed in the network analysis, where we find no contractors or other similar parties that are commercially exploiting active distribution networks or related technologies. There are a lot of ICT based consumer appliances that have reached market maturity, but these appliances are generally restricted to the management of the energy flows within the house itself. Examples of these kind of appliances are the PowerRouter by Nedap, the Plugwise system and the Qbox by Qurrent. Appliances that actually enable to control power flows to and from consumers are still not commercially available and mostly still being developed in projects funded by subsidies and private research budgets.

An active distribution network appliance that could become commercially interesting in the future is the PowerMatcher system, which has been developed by ECN and the Flemish institute for technological research and is now adopted by IBM and TNO. This system allows to level out supply and demand of electricity with each other, while respecting the physical boundaries of the distribution grid. The system will be put in operation in the Couperus project, where the PowerMatcher system is going to be tested to keep the power levels of 300 heat pumps under control. While this cluster of heat pumps would normally require a huge reinforcement of the electricity grid to cope with incidental peak demands, the PowerMatcher system enables the DSO to limit the power consumed by the heat pumps within the limits of the distribution network. A similar application of the PowerMatcher system has been seen in the

PowerMatching City project, where several wind turbines and household applications were linked together in order to optimally use the renewable energy produced by the wind turbines. Within those distribution grids, that contain large producers or consumers of electricity, the application of active distribution network technologies will first be viable and as such these grids can provide a niche market for these technologies.

4.2.6 Legitimacy

Legitimacy is very important for active distribution networks, as it will be necessary to get all the actors onboard and to get the end-users involved. The end-users are especially important in this case, since they are all affected by the transition. The importance can be illustrated by the following example: In 2009 the Dutch government attempted to introduce a new law that obliged the installation of smart meters. But after firm resistance and negative publicity from consumer privacy advocates the government decided to cancel this obligation. The transition to active distribution networks might also meet such resistance, since an active distribution network grants the DSO with a certain amount of control over the power flows on the distribution grid. They can for example be given the control to shut down generators to protect the distribution network from overloading or they could remotely control consumers appliances, such as dish washers and EV charging. This often means that consumption data of the connected users is required to control the power flows in an optimal way. This exchange of this consumption data can easily be perceived by consumers as a violation of their privacy. Additionally, because the transition to active distribution networks will eventually affect all end-users connected to the distribution grid, it is of an increasing importance to create sufficient societal legitimacy or public acceptance for the transition. The innovation adviser from the Dutch agency AgentschapNL even mentioned the lack of attention for the end-user as the most serious barrier for the transition to active distribution networks. According to him the main problem will be a failure of the involved actors in addressing the concerns that exist with end-users. The interviewees from the DSOs acknowledge this pitfall and stress the importance to think from the end-user point-of-view. Or as it was stressed by the specialist innovation from Stedin: "*Only when the products or services of an active distribution network match the needs and characteristics of the end-user can it become a success*".

But legitimacy does not only cover the end-users. Also the involved actors within the system that will need to put investments and efforts in realizing the transition should agree on the necessity of the transition. When it comes to these actors the general opinion is that the transition will be unavoidable. This was also stressed by one of the interviewees who stated: "*it is no question whether the transition is going to happen, but the question is when the transition will happen*". This strong believe in the future transition is also articulated in policy from the European Union. The European Union identifies smart grids as an important prerequisite for enabling a low carbon energy system (EC COM 112/4, 2011) and has therefore been placed the topic high on the European research and regulation agenda's. The EU considers the development of a pan European electricity grid essential in utilizing the full potential of renewable sources, allowing countries to exchange electricity in times of fluctuating availability of those renewable sources. The European Union ordered their member states to do a societal cost/benefit analysis for smart grids and announced that they will monitor the progress of implementation of smart grids in member states and, if they deem it necessary, "*will introduce stricter regulation for the implementation of smart grids*" (EC COM 202, 2011). The strong legitimacy from the EU and the mandates on smart grids are likely to have influenced the legitimacy for the transmission in the Netherlands.

But while there is not much doubt about the necessity of the transition in the future, some actors did utter their doubt about the current urgency of the transition. According to an interviewee from Kema the passive attitude of the government towards renewable energy reduces the direct need and therefore willingness of actors to engage in the transition. Instead most actors prefer to wait to see which way the cat jumps. This finding was backed up by Stedin, who claimed that they had very few distribution grids where capacity problems, for example due to DG, had arisen. The taskforce 'Smart grids' also states: "*the large-scale implementation of smart grids is at this moment not urgent, however it is unavoidable.*", which seems to capture exactly the attitude of most actors in the system.

4.2.7 Resource mobilization

The mobilization of sufficient resources is an important prerequisite for all of the system functions. For the active distribution networks there is a strong requirement for sufficient financial resources, since transforming such a comprehensive infrastructure will demand large scale investments. The government has twice provided subsidies that supported active distribution network related projects. First the EOS program provided subsidies for about 10 active distribution network related projects and after that a new scheme (IPIN) was launched that provided an additional 16 million euro to support new pilot projects. These subsidies have so far been able to provide support for quite a number of small scale research and pilot projects. This is also confirmed by the Dutch DSO Enexis who claims to have no real trouble in finding financial resources for their current (small scale) projects. However, it is still rather unclear who will in the end be responsible for the large scale investments. Enexis confirms that with the current laws and regulations they foresee problems in freeing up enough financial resources to support all the necessary developments up to 2020, which mainly concerns the large scale roll out of active distribution networks. And according to the Specialist Innovation from Stedin the cooperation between interested parties for a lot of future projects runs smoothly, until the point is reached that "*the wallet needs to be drawn*".

5. Analysis

Now that a description of the structural components and the system functions has been provided, some attention can be given to the interactions between them. Over time, functions influence each other and virtuous circles can be triggered. In our innovation system we could identify some of these circles that influence the development of the innovation system. Central we found that there is a lack of *Guidance of the search*. There is a lot of uncertainty and there are different expectations about how the future scenario of active distribution networks will look like. The reason for this is twofold. First there is a lack of soft- or social-economical *knowledge development*. With this we mean that it is at this moment unclear how the business model will have to look like and what role each actor will play in the future. Related to this we have also found a lack of knowledge about the characteristics and the behavior of the end users, which makes defining a business model even harder. The reason that this type of knowledge is largely absent is because there has been a lack of *entrepreneurial activity* on this area that could provide the required insights. Second, having a negative influence on the *guidance of the search,* we found that the government has little vision when it comes to the future energy and electricity system. This is mainly caused by their market focused policy that aims to give the market a primary role in selecting and defining future energy technologies and developments. This lack of vision does not only resonate in the *guidance of the search* function, but also seems to influence the *legitimacy* of the transition. System actors are found to strongly agree on the necessity of the transition, which can be largely explained by a strong positive influence from Europe, but we also found that a sense of urgency lacked. This lack of urgency is probably explained by the passive governmental policy which has led to a slow down of the energy transition in the Netherlands.

The lack of *guidance of the search* also influences the *resource mobilization.* Because of the uncertainty about the role each actor has to play and about where the costs and benefits are going to land investors are not willing to invest yet. Part of this uncertainty comes from the lack of knowledge on social economical issues we identified earlier. The exact earnings and savings are still unknown and will depend on the behavior of the end-users and the structural organization of the active distribution network. But part of the uncertainty can also be linked to the current outdated laws and regulations. As explained these laws and regulations limit the DSOs in their ability to do long term investments in innovations for the distribution grid and leave much debate about which actors will own and be in control of certain aspects of the active distribution grid.

The *market creation* function also showed little activity so far. A commercial (market-ready) deployment of active distribution network technologies is at this moment not yet ready. Here we can also see that laws and regulations would conflict with most commercial applications, so they would simply not be possible at this moment. As an example, Dutch law obliges that DSOs should always be able to deliver peak demand. Because this means that any application of an active distribution network should be implemented in combination with traditional network reinforcements it will be impossible to exploit it in a commercially viable way. Therefore a successful formation of the market will have to go hand in hand with a revision of the law. But also the lack of *guidance of the search* and the lack of softer *knowledge development* make that market creation is not an issue yet.

From the influences we have found we can see that some sort of negative virtuous circle emerges that starts with the lack of *entrepreneurial activity.* This affects *knowledge development*, which in turn negatively influences the *guidance of the search*. This then affects the *market formation* function and the *resource mobilization*. Meanwhile unfavorable laws, regulations and policy also negatively influence a lot of the functions. The starting point to resolve a lot of these barriers seems to stimulate the *entrepreneurial activities* and to create more favorable *institutions*. In combination with the robust network, the heterogeneous actors base, the vast amount of technological knowledge and the smooth diffusion of information and knowledge, we expect that stimulating the *entrepreneurial activities* will result in positive interactions that will be able to lead to a stimulation of the other functions.

6. Conclusion

After analyzing the innovation system for the transition to active distribution networks we can conclude that regulations are at this point not the only barrier to innovation. In this research we have shown that there are several other barriers to the transition to active distribution networks. Our results indicate that there is a system-wide need for more experimentation and trial-and-error with the technology and applications of active distribution network. These *entrepreneurial activities* are believed to provide important knowledge about social economical matters, such as the behavior of the end users and a viable business model. This knowledge will likely be able to provide more *guidance of the search*, which can help to establish a shared vision within the system on how the transition will unfold itself. At this point it will be important to change the rules of the game, thus to alter the institutional environment and to revise the laws and regulations so that they are able to facilitate the envisioned transition of the distribution network. These revisions should provide sufficient *financial resources* for the required large scale investments and will also stimulate the *formation of a market,* since commercial applications become viable within the new laws and regulations. During this whole process it is important not to let the end-users get out of sight, since a mismatch between the needs of the end-user and the architecture and applications of the active distribution network could still cause the transition to (partly) fail. Also, a more proactive government with more favorable energy policies could further stimulate the implementation of future energy technologies that will benefit from active distribution networks. This can help to create more urgency and legitimacy for the transition, which in turn can lead to the availability of more resources and less uncertainty about how the transition will unfold itself.

As for the answer to our research question we are now able to indicate several barriers that are currently hampering the transition to active distribution networks. First, there is a lack of pilot and demonstration projects. Second, there is not enough knowledge when it comes to social-economical issues. Third, there is too much uncertainty among system actors about how the transition will unfold itself. Fourth, the laws and regulations are outdated and would not allow any kind of transition at this moment. Five, there is too little attention for the needs of the end-users. And six, the passive attitude of the government leads to a lack of urgency and legitimacy. However, merely summing up these barriers in this fashion does not do justice to the complex and dynamical character of the innovation system. Instead these barriers to innovations are highly related with each other and cannot be resolved separately. One cannot fill the social economical knowledge gap without addressing the lack of entrepreneurial activity. And increased legitimacy has to result from a more proactive policy of the government. Insight in the relatedness between these barriers will be crucial in dealing with them in the future. We have proposed that stimulating the entrepreneurial activities functions, in combination with more favorable regulations, would make a good starting point to resolve the barriers to the transition to active distribution networks. Furthermore we propose that monitoring the development of the innovation system is necessary in the future to see whether our recommendations have the desired effect, thus whether a virtuous cycle is indeed triggered that helps resolve the barriers to the transition to active distribution networks.

As for now the developments within the innovation system seem to be heading the right way. The recently launched governmental program 'intelligente netten' is specifically aimed at pilot and demonstration projects that help to resolve a lot of the socio-economical questions that still remain. According to the director smart energy from Kema this program received about 20 requests for subsidy. An example of one of those projects that requested subsidy from the IPIN scheme is a pilot in the city of Breda where DSO Enexis aims to find out to what degree end-users will respond to flexible electricity prices. With regard to the problems that might arise with laws and regulation a study was done very recently by the agency AgentschapNL. They reviewed the current laws and regulations in relation with the transition to active distribution networks. These developments suggest that the barriers we have identified are generally acknowledged by the industry and are being worked on. But as we just already stressed, monitoring of the progress of the development of the innovation system in the future is necessary to see whether these efforts actually manage to stimulate the functions which we could identify as barriers to the transition to active distribution networks.

7. Discussion

While the mainly economically oriented literature on distribution networks has not yet looked beyond regulations in relation with innovations in the distribution network, our research has shown that there are other factors at stake that affect the transition to active distribution networks. This research should therefore be conceived as an addition to this economically oriented literature since it has helped to give a broader understanding of the difficulties and pitfalls that are at stake when engaging in a far reaching system transition such as is the case with active distribution networks. By analyzing the innovation system in all of its aspects we have tried to expose the many complex interactions and processes that are crucial to make the transition to active distribution networks. Most importantly, we have also attempted to expose where some of these interactions and processes were failing and how they were hampering the transition.

The main lesson on innovation that should be drawn from our research is that when it comes to technological change it is important to get a clear understanding of all the complex relations, interactions and interests that are at stake. Even though (failure of) innovation might appear to be obvious to an external observer, it rarely is. By getting a better understanding of the innovation system of active distribution networks and all of its complexities that can be found beneath its surface one is able to get a better understanding of technological change and can hopefully address the barriers that we have exposed in our research more effectively.

In terms of our method we have also aimed to contribute to the application of social network analysis in combination with the theory of innovation systems. In our opinion the social network analysis is a powerful tool that can help unravel and clarify a lot of the complex interactions and dynamics within the innovation system. Its advantage mainly lies in its ability to provide a very structured overview of the actors and the network in the innovation system and its ability to analyze the network statistically. By using a dynamical social network analysis, which shows the development of the network over time, it could even be very well used to analyze the interactions between the system functions. Because of these advantages we would recommend innovation system scholars to consider to include the social network analysis in their future research.

Of course our research also has its limitations. The social network analysis incorporates only publicly known projects and neglects any activity that is done within the boundaries of private firms or that is done using informal cooperation between system actors. Also we have assumed that all actors that cooperate within a project have an identical and bilateral relation, while in reality this will probably not be the case. In this research we have tried to overcome these difficulties by doing six interviews with experts in the field, hoping that we were able to colorize the rather static data retrieved from the social network analysis.

A second issue is that innovation systems that have been about for a longer period of time can provide more empirical evidence for interactions than a recently developed innovation system can do. This is because the interactions happen over time and might take a longer span of time to be revealed to the observer. For example, if extra financial resources are provided one could expect that this might lead to more entrepreneurial activity. But it might take several years before those resources actually result in concrete projects. This means that if one wants to get more accurate insights in the development of the innovation system its history needs to be studied over a longer span of time. Since the innovation system described in this research is still in a very early stage of development, the amount of interactions and the accuracy at which we could the describe the interactions was rather limited.

A final issue is that innovation is an increasingly globalized process, meaning that there are a lot of international cross-boundary influences that can influence the development of the innovation system. This also applies for the transition to active distribution networks, where a lot of developments take place on a European level. Even though the actual transition will largely be bound to the nation, the institutions and its infrastructural characteristics, a lot of research and regulations come from Europe. For this research we tried to deal with this by including these activities on a European level as external influences on our innovation system. But the downside of this one-directional linear approach is that possible interactions, i.e. the dynamics, between the national and European level are neglected. Enlarging the spatial scope of the innovation system, by Including other member states and European actors and institution in the analysis, might be a comprehensive task, but could do more justice to the dynamical interactions between the national and European level. Future case studies on innovation systems should take this increasing globalization of innovation in consideration and carefully decide where the system can be delineated.

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Appendix A: interviews and interview questions

	Title	*Company*	*Date*	*description*
1	Project advisor EOS	AgentschapNL	05-08-2011	Dutch agency for the implementation of policy
2	Innovator	Enexis	24-08-2011	One of the three largest Dutch DSOs
3	Director smart energy	Kema	22-09-2011	Energy related engineering and consultancy firm
4	Specialist Innovation	Stedin	17-08-2011	One of the three largest Dutch DSOs

Part of innovation system	*#*	*Question*
C1: Actors	1	Is the actor base heterogenic enough? Or are there actors missing?
	2	Which actors are most important for the transition? Which actors play a leading role in the transition?
	3	If yes, do those actors pick up that role?
C2: Network	4	Are the actors interconnected with each other? Or are there isolated clusters?
	5	How are the connections with European parties and projects
	6	Is the network clear? Are you well aware of which actors are active in the network?
C3: Institutions	7	Are the current laws and regulations fit to support the transition to active distribution networks?
	8	How does the Dutch policy relates to the active distribution networks
	9	Is there an important role for Europe to stimulate the transition? Or are member states mainly responsible themselves?
F1: Entrepreneurial activity	10	Is there sufficient experimentation with the technology and its applications
	11	Do those activities contribute to the development and diffusion of the technology?
F2: Knowledge development	12	How is the current level of knowledge development and what is the current focus?
	13	What kind of knowledge is still missing or what knowledge needs to be developed next?
	14	What are the most important sources for the development of knowledge?
	15	How is the cooperation between industry and research institutes?
	16	Is the development of knowledge competitive in comparison with other countries and/or continents?
F3: Knowledge diffusion	17	How is the level of exchange and difussion of knowledge? Is it adequately?
	18	Does the knowledge end up with the right actors in the system?
	19	How is the exchange of knowledge between Europe and the Netherlands?
	20	At which way is the knowledge mostly diffused? (conferences, papers, etc)
F4: Guidance of the search	21	Is there a shared vision on the development of active distribution networks among actors?
	22	Are there specific targets from the industry or governments?
	23	What is your expectation of the technology?
F5: Market creation	24	Is there so far any active distribution network technologies or applications that are commercially available or in use?
	25	If yes, what kind of technologies and applications?
	26	If not, for what reason?
F6: Resource mobilization	27	Are there sufficient financial resources?
	28	Which actors are going to be the main investers?
	29	Are the right people available, when considering the level and type of education?
F7: Legitimacy	30	How is the public opinion regarding active distribution networks
	31	Is there are firm believe in the necessity of active distribution networks?
	32	What are the most heard arguments against and pro the transition?
Final question	33	What are currently the most important barriers to the transition to active distribution networks?

Appendix B: Social network analysis

List of included projects for the social network analysis.

Number	*Project Name*	*Based*
1	DEVS	NL
2	EIT (Elektrische infrastructuur van de toekomst)	NL
3	Flex Power Grid Lab	NL
4	FLEXIBEL	NL
5	Geïntegreerde micro-wkk's als Virtual Power Plant	NL
6	ITM (Intelligent E-Transport Management)	NL
7	KTI (Kwaliteit van de spanning in het toekomstige elektriciteitsnet)	NL
8	Smart Grid Nieuwveense Landen Meppel	NL
9	Pilot Smart Storage	NL
10	Powermatcher	NL
11	PowerMatching couperus	NL
12	PowerMatching City hoogkerk	NL
13	Regel- en reactievermogen: spil in een duurzame energievoorziening (RegelDuurzaam)	NL
14	SA sensoren	NL
15	SINERGIE	NL
16	Smart power city apeldoorn	NL
17	SmartProofS	NL
18	TREIN-01	NL
19	TREIN-02	NL
20	Weilandproeven	NL
21	Smartsubstation (IntDS)	NL
22	EDSO SG	EU
23	IMPROGRES	EU
24	SMARTGRIDS ERA-NET	EU
25	ADDRESS	EU
26	FENIX	EU
27	MICROGRIDS	EU
28	DISPOWER	EU
29	DG FACTS	EU
30	SUSTELNET	EU
31	INTEGRAL	EU
32	Smarthouse/smartgrid	EU
33	TWENTIES	EU
34	SUSPLAN	EU
35	EU DEEP	EU
36	OPENNODE	EU
37	INTEGRIS	EU
38	MIRABEL	EU
39	W2E	EU
40	DLC+VIT4IP	EU
41	HIPERDNO	EU
42	DG-GRID	EU
43	DER LAB	EU
44	SOLID DER	EU
45	DGNET	EU
46	MORE MICROGRIDS	EU
47	ADINE	EU

Dutch projects and their corresponding actors

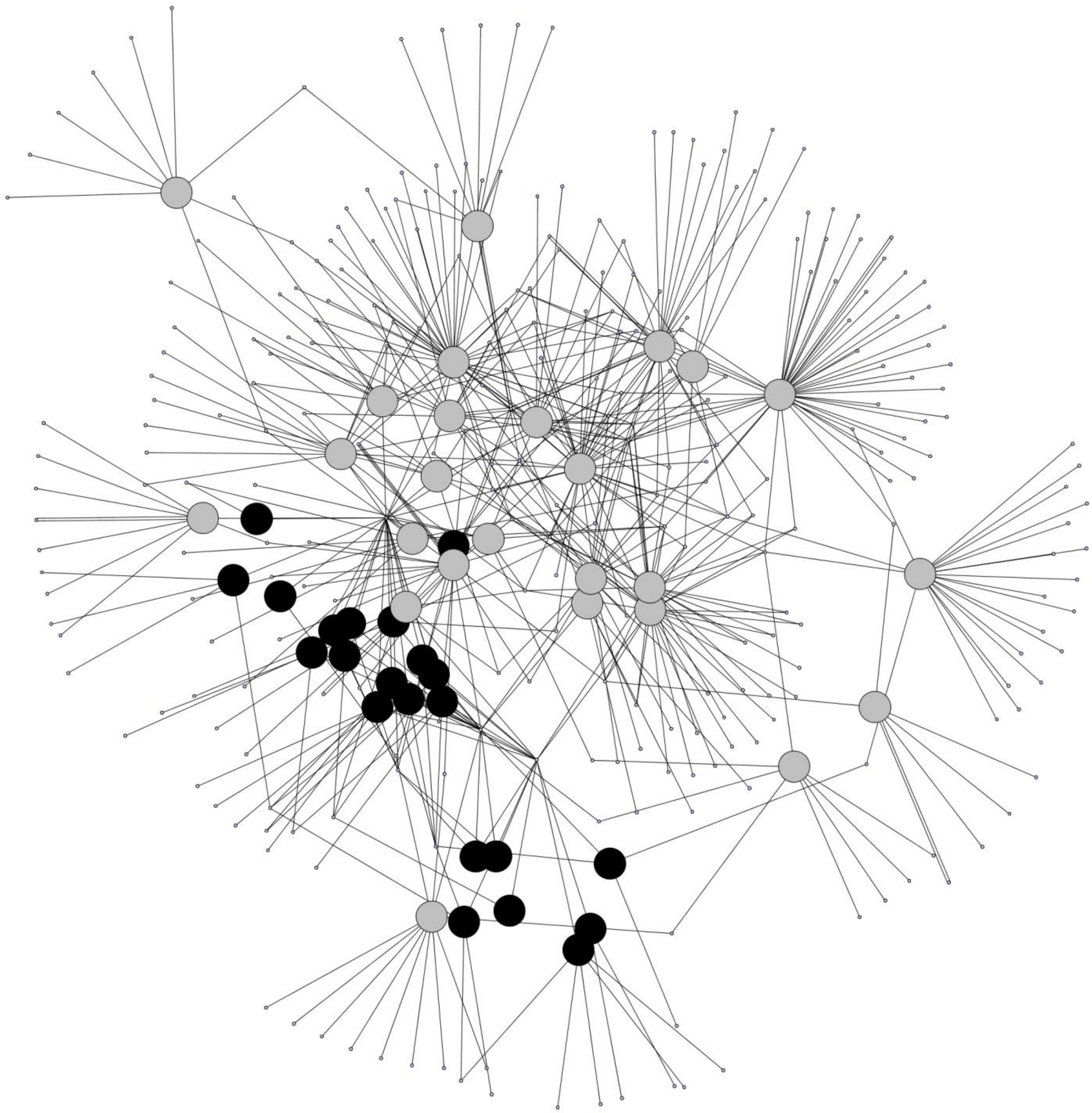
#	*Project name*	*Participants*
1	DEVS	Alliander, ECN, Kema, TU Delft
2	EIT (Elektrische infrastructuur van de toekomst)	ECN, Kema, TU Eindhoven
3	Flex Power Grid Lab	ECN, Kema, TU Delft, TU Eindhoven
4	FLEXIBEL	ECN, Kema, TU Eindhoven
5	Geïntegreerde micro-wkk's als Virtual Power Plant	ECN, Gasunie
6	ITM (Intelligent E-Transport Management)	Alliander, ECN, Enexis, IWO Institute for Science and Development, Kema, Stedin
7	KTI (Kwaliteit van de spanning in het toekomstige elektriciteitsnet)	ECN, Laborelec, TU Eindhoven
8	Smart Grid Nieuwveense Landen Meppel	Enexis, Gemeente Meppel, Kema, Ministerie van ELI
9	Pilot Smart Storage	Alliander, ECN, Enexis
10	Powermatcher	ECN, VITO
11	PowerMatching couperus	ECN, Eneco, ltho, Stedin, Vestia
12	PowerMatching City hoogkerk	ECN, Essent, HUMIQ, Kema
13	Regel- en reactievermogen: spil in een duurzame energievoorziening (RegelDuurzaam)	APX-ENDEX, ECN, GPX, Kema, TenneT, TU Delft, TU Eindhoven,
14	SA sensoren	Alliander, Locamation, Phase to Phase
15	SINERGIE	Alliander, TU Delft
16	Smart power city apeldoorn	Alliander, GasTerra, Gelderland, Gemeente Apeldoorn, Nuon, Remeha
17	SmartProofS	Alliander, ECN, Enexis, HUMIQ, Stichting Energy valley, TNO
18	TREIN-01	Alliander, Kema, TU Eindhoven
19	TREIN-02	Alliander, Kema, TU Eindhoven
20	Weilandproeven	Alliander, Enexis, GasTerra, Smart Power Foundation, Stedin
21	Smartsubstation (IntDS)	Alfen, Alliander, Eaton, ECN, Exendis, Imtech, Kema

This table shows the Dutch actors and the value of their statistical measures.

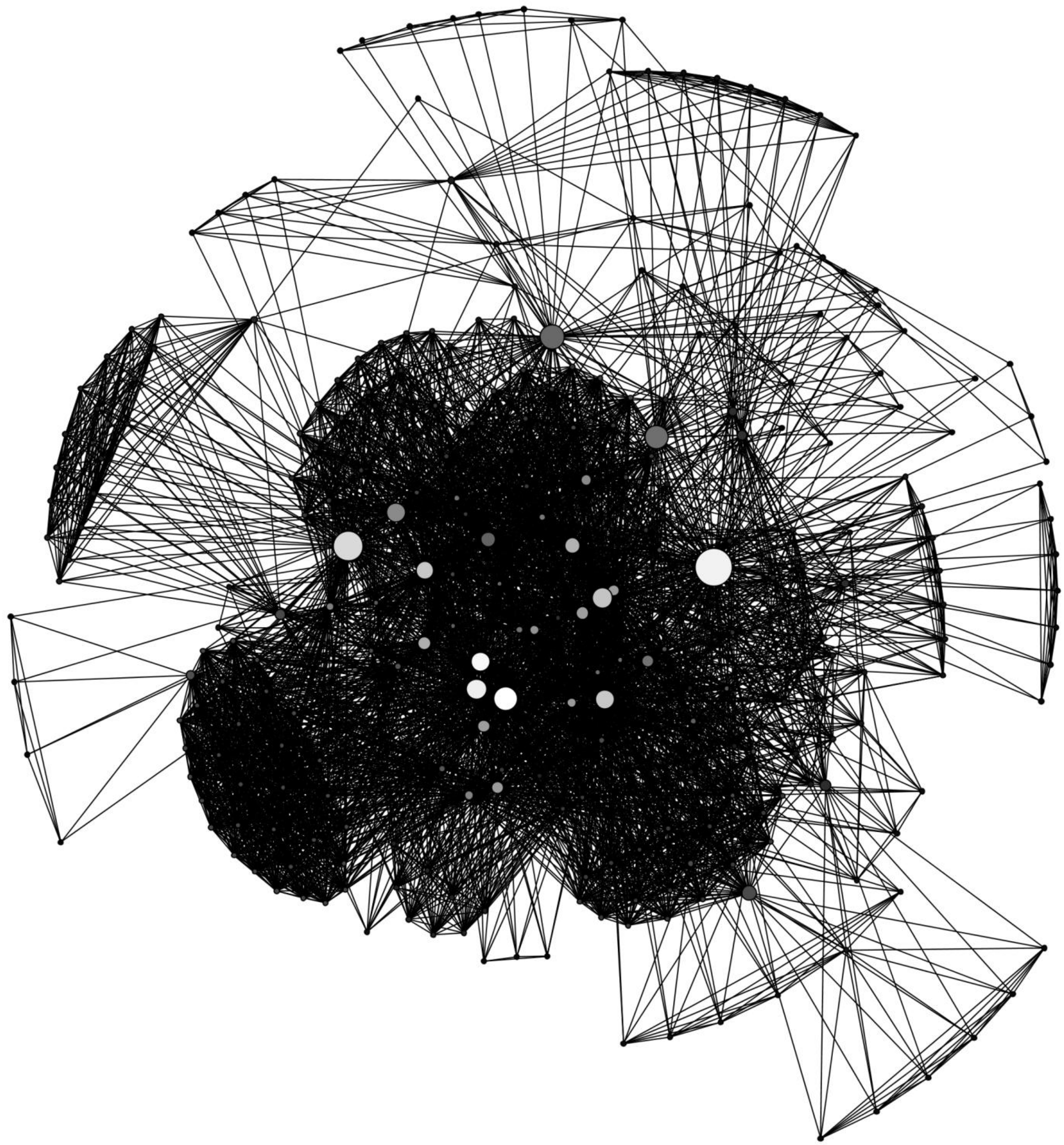
Actor	*closeness*	*degree*	*betweenness*	*clustering coefficient*
ECN	0.00238	139	6418.651	0.206
Kema	0.00204	65	2497.404	0.244
Alliander	0.00200	61	2683.898	0.340
APX-ENDEX	0.00188	41	94.760	0.805
TenneT	0.00182	30	92.385	0.729
Emforce	0.00181	35	4.420	0.882
Ecofys	0.00178	37	0.000	1.000
Philips	0.00172	20	0.000	1.000
VU Amsterdam	0.00170	18	0.000	1.000
TNO	0.00170	12	112.513	0.515
TU Eindhoven	0.00170	8	8.932	0.679
Enexis	0.00166	12	131.127	0.424
Ministerie van ELI	0.00163	23	191.295	0.767
TU Delft	0.00161	7	4.012	0.857
HUMIQ	0.00160	7	9.572	0.714
Stedin	0.00159	10	89.578	0.467
Gasunie	0.00159	8	0.000	1.000
ICT Automatisering	0.00159	8	0.000	1.000
Alfen	0.00158	6	0.000	1.000
Exendis	0.00158	6	0.000	1.000
Imtech	0.00158	6	0.000	1.000
IWO	0.00158	5	0.000	1.000
GPX	0.00155	6	0.000	1.000
Stichting Energy valley	0.00153	5	0.000	1.000
Essent	0.00151	3	0.000	1.000
Eneco	0.00144	4	0.000	1.000
Itho	0.00144	4	0.000	1.000
Vestia	0.00144	4	0.000	1.000
Gemeente Meppel	0.00135	3	0.000	1.000
GasTerra	0.00131	8	12.333	0.571
Smart Power Foundation	0.00130	4	0.000	1.000
Gelderland	0.00129	5	0.000	1.000
Gemeente Apeldoorn	0.00129	5	0.000	1.000
Nuon	0.00129	5	0.000	1.000
Remeha	0.00129	5	0.000	1.000
Locamation	0.00129	2	0.000	1.000
Phase to Phase	0.00129	2	0.000	1.000

List of the first 50 actors and the values of their statistical measures

#	Actor	Type	closeness	degree	betweenness	clustering coefficient
1	Iberdrola	Foreign	0.00239	146	2547	0.276
2	Labein	Foreign	0.00237	143	1639	0.295
3	ECN	Dutch	0.00238	139	6419	0.206
4	Siemens	Foreign	0.00239	137	1882	0.293
5	CRES	Foreign	0.00229	125	4116	0.299
6	EDF	Foreign	0.00223	115	1650	0.312
7	ICCS/NTUA	Foreign	0.00224	115	1438	0.343
8	Fraunhofer	Foreign	0.00226	113	1916	0.284
9	U Manchester	Foreign	0.00221	103	1096	0.329
10	U Leuven	Foreign	0.00213	101	755	0.399
11	CESI-R	Foreign	0.00211	92	557	0.426
12	ZIV	Foreign	0.00216	92	732	0.386
13	KAPE	Foreign	0.00207	91	659	0.439
14	VTT	Foreign	0.00211	91	702	0.444
15	Areva	Foreign	0.00205	90	373	0.439
16	ISET	Foreign	0.00209	86	378	0.465
17	AIT	Foreign	0.00202	80	1622	0.374
18	MVV	Foreign	0.00204	80	508	0.428
19	Laborelec	Foreign	0.00201	76	355	0.559
20	ANCO	Foreign	0.00196	74	290	0.542
21	Imperial college london	Foreign	0.00200	71	184	0.522
22	U Pontificia Comillas	Foreign	0.00200	68	636	0.370
23	ARMINES	Foreign	0.00201	67	206	0.571
24	SMA Technologie	Foreign	0.00198	67	166	0.553
25	CEA-Genec	Foreign	0.00195	65	108	0.636
26	Cogen	Foreign	0.00195	65	108	0.636
27	Kema	Dutch	0.00204	65	2497	0.244
28	U Strathclyde	Foreign	0.00196	64	158	0.542
29	Alliander	Dutch	0.00200	61	2684	0.340
30	ABB	Foreign	0.00198	58	996	0.472
31	Verbund	Foreign	0.00190	57	169	0.580
32	TU Denmark	Foreign	0.00194	56	161	0.530
33	INESC Porto	Foreign	0.00189	55	130	0.589
34	ENEL	Foreign	0.00188	54	155	0.621
35	FEEM	Foreign	0.00188	52	196	0.732
36	TU Sofia	Foreign	0.00192	51	112	0.682
37	ENERSEARCH	Foreign	0.00187	50	201	0.769
38	U Lund	Foreign	0.00176	48	358	0.815
39	poyry energy	Foreign	0.00187	47	41	0.731
40	SINTEF	Foreign	0.00185	47	163	0.524
41	Enea	Foreign	0.00186	46	79	0.639
42	Elsam	Foreign	0.00180	45	86	0.735
43	Schneider	Foreign	0.00180	45	990	0.707
44	TU Lodz	Foreign	0.00189	45	42	0.755
45	U Brunel	Foreign	0.00180	45	178	0.730
46	Energinet	Foreign	0.00177	44	520	0.515
47	Axiom	Foreign	0.00174	43	0	1.000
48	Bowman Power group	Foreign	0.00174	43	0	1.000
49	Capitalia	Foreign	0.00174	43	0	1.000
50	CENTER	Foreign	0.00174	43	0	1.000



Systematical overview of the actors and projects involved in smart grids. The blue dots represent Dutch projects, the purple dots represent European projects. The small dots represent the system actors that connected to either one or more projects.



This picture shows all the inner links between firm actors. The actors are represented in this picture by the dots, which are connected which each other by the black lines. The 'betweenness' value is graphically shown by the size of the dot (the bigger the dot, the higher the betweennes value) and the 'degree' is shown by the color of the dot (the lighter the dot, the higher the degree value). As can be seen these two centrality measures often go hand in hand, meaning that a high betweenness value often corresponds with a high degree value.