Smart game, smart rules

Exploring the institutional design of the smart electricity system

Master thesis

Environmental & Infrastructure Planning

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Preface

This is my thesis for the master of Environmental and Infrastructure at the University of Groningen, faculty of Spatial Sciences. After following the bachelor Spatial Planning and Design (Technische Planologie) I had gained an interest in infrastructure planning and the energy transition. Therefore, choosing the master Environmental and Infrastructure was a logical choice. I found it difficult to choose a research topic for my master thesis, as the master itself covers many aspects of infrastructure planning which I find interesting. My interest in the energy transition led to searching for a topic within the future energy grid. After reading articles on smart grid pilots with a role for blockchain technology, I decided to explore the topic of blockchain-based smart grids. Initially this was something I was very enthusiastic about, but after several months I found this topic less interesting and more difficult than I expected, which led to a change toward the institutional design of smart grids. Institutions and institutional designs are not necessarily things I had an interest in before writing this thesis. However, after finding out that institutional barriers form a specific problem for smart grids I saw it as an ideal research topic.

I could not have finished this thesis with the help of several people. First of all, my friends and family have always supported me and kept my spirits up when I was having stressing over the writing of this thesis. Secondly I want to thank the interviewees for having the time for participating in my research and providing me with a lot of useful data. Finally I want to thank my supervisor, dr. Ferry van Kann, for his tips, feedback and patience during the writing process of this thesis.

Herman Carel Bouma
September 2019

Abstract

The worldwide demand of electricity is growing. Electricity is to be generated from renewable sources, but fluctuations of the renewable electricity supply and a lack of energy storage options stand in the way of reaching goals for renewables, especially in the Netherlands. Adjustments to the electricity grid are required to facilitate a larger share of renewables. Those adjustments should lead to the development of a smart grid. The development of a smart grid is made difficult by outdated institutional conditions in the Netherlands as the institutional conditions are based on a conventional electricity system. But the game is about to change, and so should its rules.

Therefore this thesis aims at identifying the institutional conditions – the 'rules of the game' – that are outdated and require adjustments. Firstly, a positioning of this objective takes place to make sense of the complex situation and to formulate research questions. Secondly, an understanding of the objective takes place in the theoretical framework. Transition theory is used as a basis to form a conceptual model which is used as a tool for further research. Results show that the most important institutional barriers that require adjustments are the slow grid improvement process that is a result of protective rights, the unavailability of curtailment as an instrument and the fact that there is no incentive for end users to change their behaviour.

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Chapter 1 – Introduction

1.1. A fluctuating power supply

On the morning of Monday the 30th of April 2018, the power distribution network of the Netherlands faced a serious power shortage. Contrary to the weather forecasts of energy companies, there was little sun and wind and therefore a smaller supply of energy generated by sun and wind. As a result the Dutch energy network operator Tennet was forced to contact energy suppliers to use their emergency power supply, but this proved to be inadequate to bring stability. Tennet eventually made an extra call to suppliers from Belgium and Germany to prevent electricity outages in certain areas in the Netherlands (NOS, 2018a). A possible solution for fluctuation-related electricity shortages is energy storage, for example in the form of batteries. For this reason the Dutch energy company Eneco and Mitsubishi opened their 48 MW battery, described as the largest battery in Europe, on May 31st, 2018, in Jardelund, Northern Germany. The battery will initially be used to provide reserve capacity for European grid operators (Renewables Now, 2018). However, large-scale rechargeable battery facilities face barriers for implementation, such as relatively low cycle times and high maintenance costs (Luo et al., 2015).

Electricity has become more and more important in our daily lives, and there seems to be no end in sight of the growth of worldwide electricity use. Between 1995 and 2015, electricity use in the Netherlands increased by 29 percent (CBS, 2018). Yang et al (2011) predict that the worldwide electricity demand will be doubled by 2050 and tripled by the end of the century. Catching up on goals for renewable energy is often conflicted by problems regarding security and affordability (Bosman et al., 2014).

As the share of renewable electricity has grown significantly in recent years, it seems that the problem of a fluctuating electricity supply is a growing one. CBS (2017a) even stated that these fluctuations limit structural developments for renewable energy. Pop et al. (2018) argue that this problem is exacerbated by a lack of energy storage capabilities which lead to distribution system operators frequently curtailing the energy output of renewable sources to not endanger the entire grid operation. When weather circumstances are not so favourable for wind and solar power, fossil-based power plants have to compensate the low supply. Therefore, there is a need for energy storage to provide grid stability if a transition to renewable energy is to be made (Yang et al., 2011). There is, however little available knowledge on how to implement large-scale energy storage projects and its link to spatial planning. Such projects often have high costs, although they are decreasing (Ummels et al., 2008).

This situation leads to the need for rethinking the architecture of our energy infrastructure (De Beaufort et al., 2017). Pop et al. (2018) share this view. They state that smart grid management problems cannot be solved with centralized approaches, resulting in a need of visionary decentralized approaches for the energy system. Verzijlbergh et al. (2017) describe this as a major paradigm change, where the traditional energy system changes from few large generators that transport energy down to customers through the distribution system into a renewable energy-based power system with a growing number of generators.

Smart electricity systems – or smart grids – are considered to be the upgraded version of the electricity network with widely acknowledged benefits (European Commission, 2011). Such smart grids are often presented as a solution to deal with technical challenges with the help of information and communication technologies. Their introduction is challenged, most importantly by complex multi-stakeholder configuration and by institutional conditions. Lammers and Hoppe (2019) state that these institutional conditions (the ‘rules of the game’) are crucial for the cooperation between stakeholders, but appear to be outdated. They perceived that the current rules of the game are not appropriate for smart grid projects, as they are designed to support a centralized power supply system. The institutional conditions are also claimed to be determinants of social acceptance of smart grids, influencing the deployment of renewables (Wolsink, 2012). For creating, operating and managing an integrated smart grid, non-technical barriers need to be identified.

The Netherlands has a relatively high amount of public funding for smart grid projects in the European Union, which has resulted in twelve Dutch smart grid pilots that took place from 2011 to 2016. Large-scale deployment however is yet to happen (Lammers and Hoppe, 2019). Despite this lack of large-scale deployment, the Dutch interest in smart grid pilots illustrates that the country could fulfill an exemplary role in global smart grid enrollment.

1.2. Understanding fuzziness

Before visionary approaches can be discussed and research on certain topics can take place, it is important to discuss the character of certain concepts. The reason for this is that a difference in the understanding of a concept in governance processes can lead to issues in the decision-making process (figure 1). Planners are busy with decisions and turning decisions into desired effects, often under complex circumstances. These circumstances create a situation where questioning the meaning of basic concepts is not always considered a priority, as long as there is a certain level of understanding amongst the involved actors. However, different interpretations can exist and affect decision-making (De Roo & Porter, 2007).

Certain concepts in planning have a such a fuzzy character. Commonly used concepts such as ‘sustainability’ and ‘the compact city’ are to some extent fuzzy. Fuzzy in this case means that a concept can have a fluidity of meaning. Such concepts on the first hand might seem to contain a clear ambition, but are not understood as well as one might think. For example, ‘sustainability’ is widely accepted as one of the most important goals of planning but has no clear practical application. Because of this fact, different understandings of a concept can exist and concepts are open to interpretation based on an individual’s position. In the institutional arena attempts can be made to give a fuzzy concept an operational meaning, but this can result in struggles over its interpretation. Because of those different understandings, such fuzziness can be seen as actor-related fuzziness in planning. De Roo & Porter (2007) state that for dealing with fuzzy concepts in planning a mutual understanding among actors is likely to have a positive effect on the planning process and its outcomes. Seeking such mutual understanding can help the planning process, as individuals can bring new insights to making concepts operational. Therefore, consultation is needed. Paying no attention to the fuzzy character of concepts in governance processes can lead to several issues as can be seen in figure 1. De Roo & Porter (2007) propose an actor-consulting model that can help to create a common understanding of a fuzzy concept. The resulting information can be used by decision-makers as uncertainty surrounding fuzzy concepts is reduced.

If issues regarding fuzziness are not addressed, there could be a lack of clarity among the involved actors regarding each others responsibilities and roles.

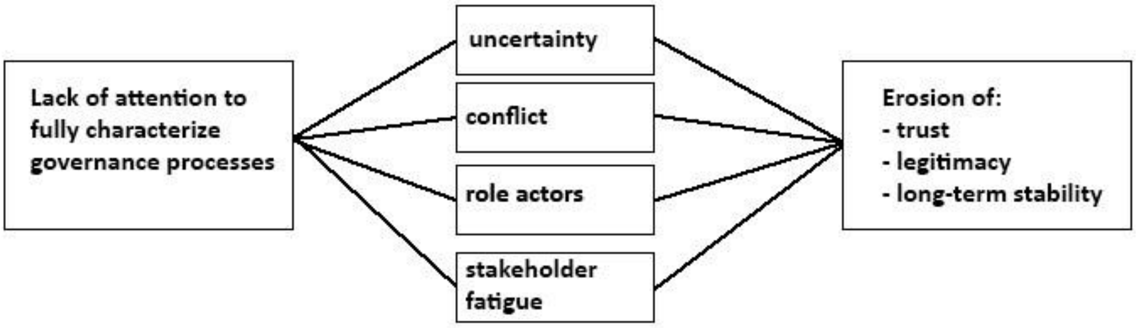

Figure 1: Possible consequences of lack of attention for the fuzzy character of governance processes (De Roo & Porter, 2007).

When the issues regarding uncertainty, conflict, role-abuse and stakeholder fatigue grow, they will likely affect governance processes in a negative way. Figure 1 shows how trust, legitimacy and long-term stability of governance processes can be affected when fuzziness is not addressed. In such a situation actors might inadvertently act in conflicting ways, thinking that their actions are actually contributing to reaching a goal based on a fuzzy concept, such as 'sustainable development'.

To summarize, the approach in planning should be inter-subjective or institutional when the complexity of a given issue rises. This way, the focus is on optimizing the planning process rather than maximizing the planning result in line with the predefined goals. This perspective makes it possible to look at the actions of actors within the planning process in a more critical and reflexive way.

This research focuses on a complex problem and contains key concepts that can be seen as fuzzy, such as the mentioned examples of sustainability and smart grids. It is therefore important to take an inter-subjective approach when discussing actor-related fuzziness regarding these concepts and to find mutual understanding. For the rest of this thesis the fuzziness of the concepts 'smart grid' and 'institutional design' will be taken into account. Those concepts are key concepts that occur in this thesis and therefore require a good understanding of their meaning. This would ideally involve inter-subjective input from actors as the fuzziness is actor-related. Because of practical reasons this thesis will mostly gather input from literature and desk research regarding the fuzziness of those concepts.

It should also be noted that so far 'energy' and 'electricity' have already appeared several times on the previous pages. Terms such as 'energy production' and 'energy consumption' are often used, but are not in accordance with the laws of thermodynamics. The first law of thermodynamics states that energy cannot be produced and cannot be depleted or destroyed. This means that the total amount of energy in the universe will remain the same. The quality of energy, however, will not. Conversion of energy is needed to allow energy to be used for processes and activities. In this process of conversion, exergy is consumed and the quality of energy is reduced (Van Kann, 2015). Still, many sentences that do not comply with the laws of thermodynamics are used in common practice. In order to achieve a better readability of this thesis I have chosen to use such terms and sentences as well. I believe this will not have any influence on the effectiveness of this research as the focus is mainly on smart grids rather than energy conversion.

1.3. Reaching goals

The Netherlands is currently striving to improve its production of renewable energy. This is needed, as the Netherlands is not doing too well when compared to the rest of Europe and has a long way to go to reach the set targets. As can be seen in figure 2 below, only Luxembourg has a lower share of energy from renewable sources.

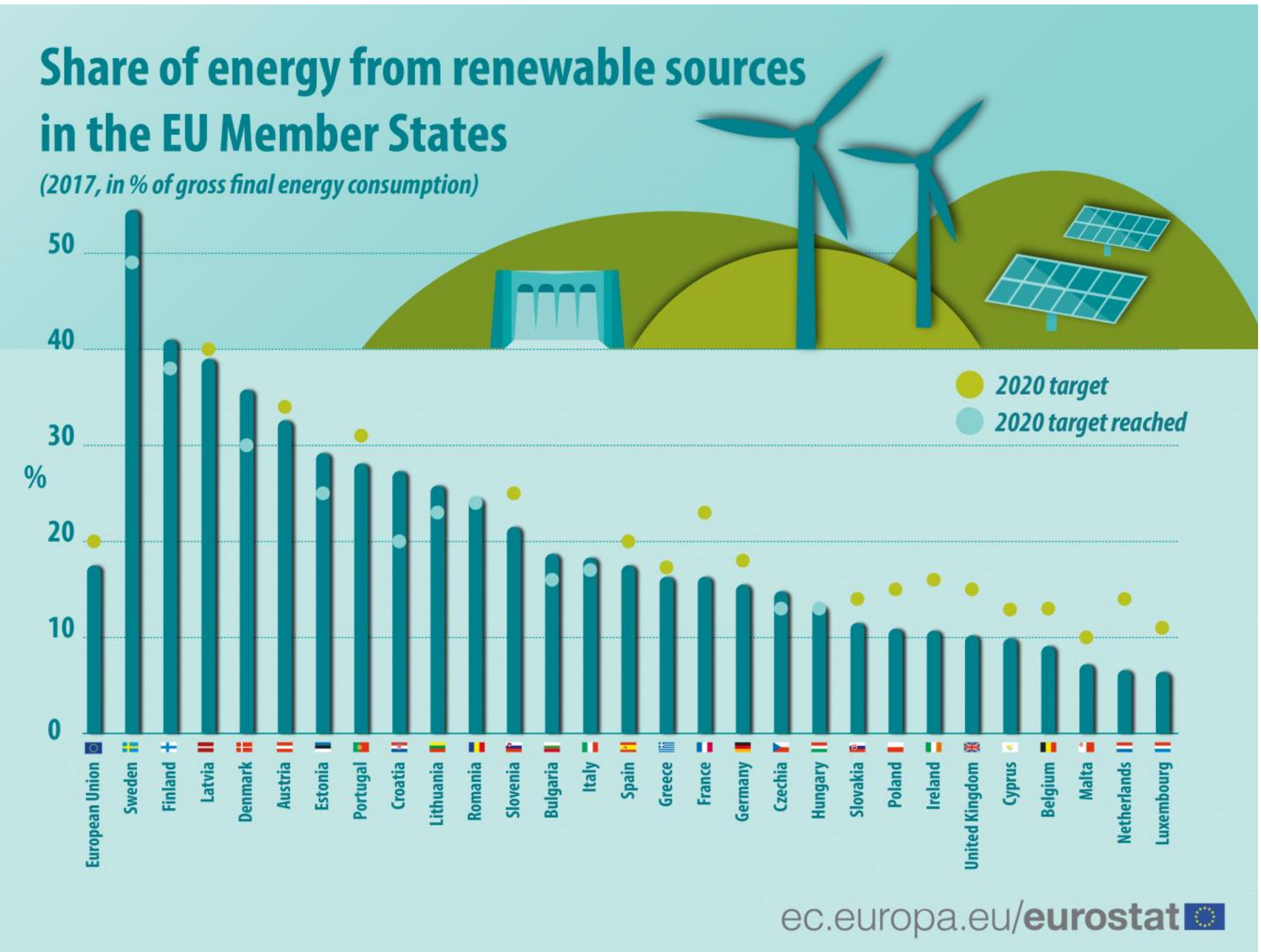

Figure 2: The share of energy from renewable sources in the EU Member States (Eurostat, 2019).

Of the total energy consumption in the Netherlands, 14 percent needs to be coming from renewable energy (biomass, wind energy, solar energy, hydropower, geothermal energy and ambient air) in 2020 (CBS, 2017a). Between 2015 and 2016, this amount increased from 5,8 percent to 6 percent of which biomass was the most important contributor with 63 percent, followed by wind energy with 24 percent. Of the renewable energy, 49% was used for heating, 43% for electricity and 8% for transport. Looking at electricity generation specifically, CBS (2017a) noticed that the contribution of renewables grew from 11 to 13%. It is striking that the electricity production by wind turbines and solar panels increased in 2016 by 21 percent and 39 percent respectively (CBS, 2017a).

The Dutch Ministry of Economic Affairs has stated in its Energy Agenda that by the year 2050 the country needs to reduce its usage of fossil energy to a percentage close to zero (Ministry of Economic Affairs, 2016). This means that electricity has to be generated in a sustainable way. The Energy Agreement contains renewable energy goals for 2020 and 2023, with renewable energy percentages of respectively 14 and 16 (Ministry of Economic Affairs, 2016). As this percentage was 6 percent in 2016, the Netherlands still has a long way to go to reach its intended targets. CBS (2018b) stated that in 2017 this percentage climbed to 6,6 %. The development of this percentage since the year 2000 can be seen in figure 3. Table 1 gives an overview of the set deadlines for sustainable electricity generation.

Goal:	**Deadline:**	**Current situation:**
Sustainable electricity generation of at least 14%	2020	6,6% (2018)
Sustainable electricity generation of at least 16%	2023	6,6% (2018)
Sustainable electricity generation of close to 100%	2050	6,6 % (2018)

Table 1: Overview of renewable electricity goals for the Netherlands (Ministry of Economic Affairs, 2016; CBS, 2018b).

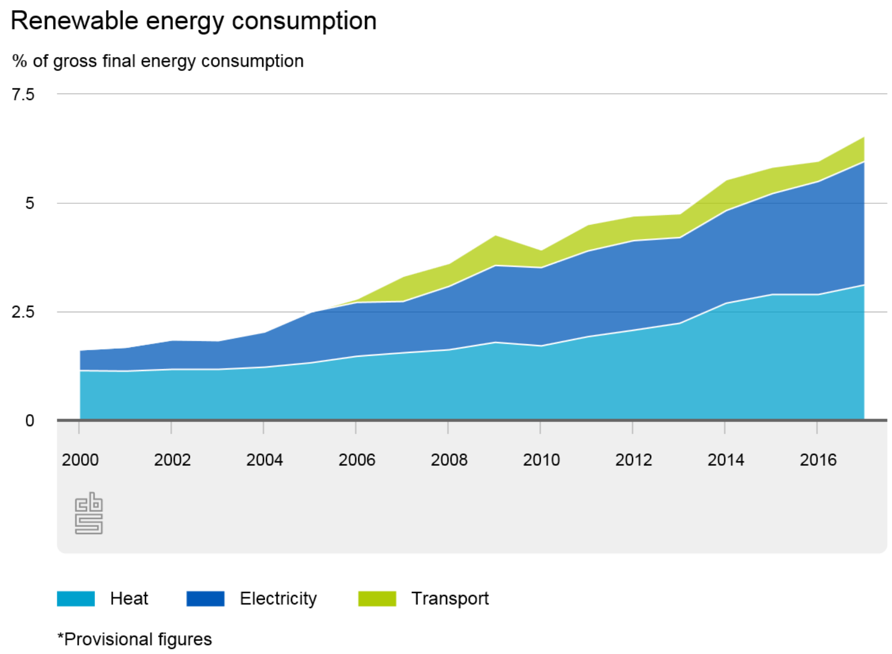

Figure 3: Dutch Development of renewable energy consumption as a percentage of gross final energy consumption since 2000 and its uses (CBS, 2018b).

Energy from renewable sources is used for heat, electricity and transport. Currently, about 50% is used for heating, 40% for electricity and 10% for transport (CBS, 2018b). However, the gross final energy consumption in the Netherlands has been stable in the last decade at around 120 billion kWh (CBS, 2017b).

It can be concluded that the Netherlands is still struggling in reaching the intended targets for sustainable energy production and specifically electricity. The 'green' shares of energy production are growing, but it seems quite some work still needs to be done. This work will not be limited to finding new ways to produce energy, but will also include rethinking the infrastructure that facilitates the increasingly fluctuating energy output and the 'rules of the game'. This thesis aims at gaining insight on the outdated rules of the game. As this is an objective in a complex context, it is important to position the objective before establishing research questions. To clarify the structure of the rest of this thesis an overview will be presented in the next section.

1.4. Reading guide

This section will elaborate on the structure of the rest of this thesis. The reason for this is to give the reader a more pleasant reading experience. Besides the introduction that has taken place in this chapter, this thesis contains the following parts:

Positioning of the objective (chapter 2)
The next chapter will focus on the positioning of the objective. Before research questions and a research strategy can be developed it is important to have a look at the problem and how it should be approached. Therefore chapter 2 will elaborate on the problem from a planning perspective, the knowledge that is required to solve this problem and the relevance for academics and planning practice. Chapter 2 results in the formulation of the research questions.

Theoretical framework (chapter 3)
Chapter 3 presents and discusses the theoretical framework of this thesis. The goal of chapter 3 is to gain a better understanding of the objective by performing a literature review. Chapter 3 results in a conceptual model that provides insight on the rules of the game based on theory. The conceptual model is afterwards used as a tool for further research.

The literature that is used in the theoretical framework comes mainly from academic journals on the topic of energy and energy policy. The reason for this is that these sources cover a broad spectrum of policy implications of energy supply and use, which are highly relevant for this thesis. The theory that forms the backbone of the theoretical framework is transition theory, which includes the phases of a transition and the multi-level perspective. Transition theory is highly relevant for this thesis as the transition from the current electricity grid towards a smart electricity grid is key. This transition also takes place in the context of the energy transition. A further elaboration on the literature of the theoretical framework takes place in chapter 4.

A desk research also has been conducted for chapter 3. Besides transition theory, chapter 3 elaborates on the Dutch electricity grid, electricity storage, smart grids and institutions. A literature review on those topics is performed and is supplemented with findings from the desk research. The reason for this is that these topics are highly relevant for this thesis and that not all information required to answer certain research questions can be gathered from academic literature alone. In the end the conceptual model connects transition theory to the Dutch grid, electricity storage, smart grids and institutions.

Methodology (chapter 4)
Chapter 4 describes the methodology used in this thesis and will make clear how the research

strategy is organized and connected to the research aim and goals. An overview of the strategy and the data collection and analysis is provided as well.

Findings and results (chapter 5)
The findings and results of this thesis are presented in chapter 5. The structure of chapter 5 is based on the theoretical framework and therefore follows the topics Dutch grid, transition theory, electricity storage, smart grids and institutions.

Conclusion (chapter 6)
Conclusions based on the findings and results are made in the final chapter of this thesis. The research questions are answered and a discussion on the limitations of this research is performed. Chapter 6 also contains recommendations on further research and a reflection on the writing of this thesis.

Chapter 2 – Positioning of the objective

A problem has been introduced in the previous chapter. Worldwide demand of electricity is growing and goals have been set to meet these demands with electricity from renewable sources. But as renewables have a fluctuating output and grid stability is very important, energy storage is required. Distributed generation from renewable sources also requires adjustments to the electricity system, which should lead to the development of a smart grid. The game is thus about to change, and so should its rules. Formulating this as an objective means that the outdated rules that need to be changes have to be identified. This chapter will position this objective in order to make more sense of the complex situation so a research strategy can be designed.

2.1. The problem - a subject for planners?

The renewable energy production needs to be increased and the complete energy grid needs to undergo technical and non-technical changes. And even after the challenge of upgrading the grid is completed the new situation will likely bring changes for involved actors, including end users and the users that start producing themselves. Does it make sense to look at this situation from a planning point of view?

It is clear that reaching the set targets for renewable energy production is being hindered by the fluctuations of the renewable energy supply and the lack of energy storage capabilities or flexibility. Our society's deep dependence on an affordable, reliable energy supply makes policy making for energy systems a risky endeavor (Collins & Ketter, 2014).

The electricity grid is a complex and comprehensive system. De Boer & Zuidema (2015) described the energy system as a complex web of interrelated networks and actors in a physical, economic, social and institutional sense. Renewables have a high visibility in the landscape and often require a lot of space, and making changes within the complex web to develop a smart grid can also be considered complex. Lammers and Heldeweg (2016) state that this brings an emergence of new actors and actor constellations, making local energy policies and planning more complex. The implementation of smart grids is influenced by a changing institutional and technical environment, as well as by the coordination of energy, resources and spatial planning. The fuzziness surrounding smart grids also contributes to this situation, as smart grid terminology is inconsistent and ambiguous (Lammers and Heldeweg, 2016).

A development toward a smart grid, would likely have consequences for many involved parties, including new actors. De Roo & Porter (2007) have stressed that in such a situation it makes sense to take the fuzzy character of important concepts into account. This way, the planning process should be improved rather than the maximization of the planning result. De Roo (2000) stated that issues regarded as complex are interwoven in a dynamic context and contain an important relationship with the context. A more open, communicative form of planning with attention for process-related characteristics rather than predefined goals is considered a suitable approach (De Roo, 2000).

Lammers and Heldeweg (2016) claim that it is important to address the governance of collective action and related legal regimes. By doing this, complexity should be decreased. Innes & Booher (2007) add to this that consensus building can be seen as an option that could change the direction of an uncertain, complex and evolving system. It links distributed intelligence of actors to form a responsive planning system that reflects on the complex, evolving and social context. This way, different interests can be incorporated and solutions that offer mutual gain can be found (Innes & Booher, 2007). Figure 4 visualizes the relation between the complexity of a system and its approaches regarding strategic planning.

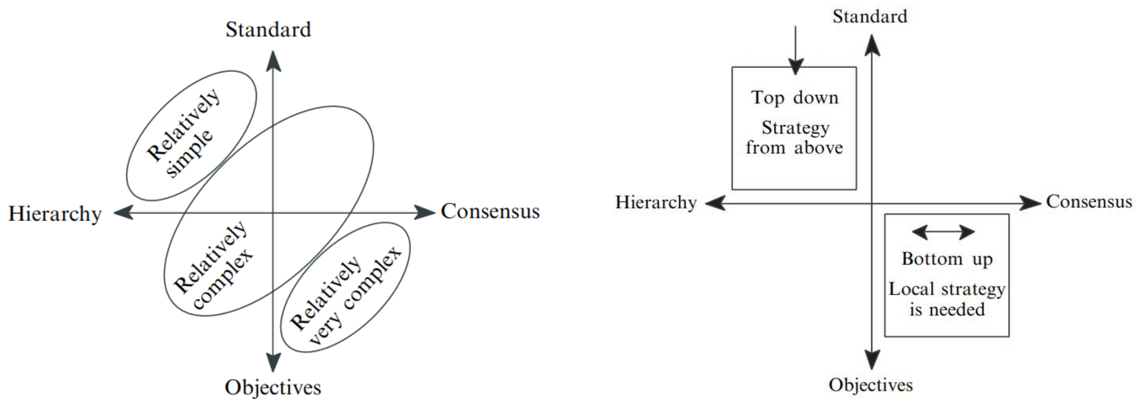

Figure 4: Assigned complexity in relation to approaches in Dutch environmental planning (De Roo, 2000).

Distributed generation

Collins & Ketter (2014) state that the traditional approach to the electricity supply and grid management is top-down. Spatial characteristics never really mattered on the subject of a traditional energy supply (Van Kann, 2015). Kroposki & Mather (2015) argue that the electric power system grew around the idea of economies of scale – *"the bigger the power plant, the cheaper the electricity"* (p. 14). They add that the grid was fundamentally designed for a relatively small amount of large central generators, with power flowing in one direction. One could argue that there is a traditional approach for a changing system that is increasing in complexity. Connecting this to figure 4, it means that a local strategy makes more sense rather than keeping the traditional, top-down approach.

Aitzhan & Svetinovic (2018) identified two main drawbacks of a centralized energy trading system, being concerns regarding a single point of failure and a lack of privacy and security.
Low-cost distributed generation, especially in the form of solar photovoltaics, has become quite noticeable recently. This large-scale deployment of distributed energy resources brings challenges to the current grid. The traditional approach is being disrupted by distributed renewables and the possible need for a change in behavior of energy consumers. Energy consumer behavior would have to adapt to the availability of renewable energy resources. The growth of utilities that are organized to generate and sell energy seems to be limited by small-scale distributed generation, environmental regulation, slow population growth and increasing efficiency (Collins & Ketter, 2014). Lammers and Hoppe (2019) concluded, after studying several smart grid pilot projects in the Netherlands, that the institutional conditions are outdated and not at all helping the realization of smart grids. This finding suggests that the rules of the game are still following the traditional, top-down approach. But as the game is about to become fundamentally different, the rules need to be reconsidered.

So does is make sense to look into the issue from a planning point of view? The electricity grid has been designed with a traditional, top-down approach of environmental planning. The complexity of the grid is rising and Lammers and Hoppe (2019) have stated that the 'rules of the game' are considered outdated. Figure 4 would suggest that an bottom-up approach of environmental planning is more suitable during the reconsideration of the rules of the game, meaning that the relationship with the context is important and an open, communicative form of planning with attention for process-related characteristics rather than predefined goals is favorable. As section 1.2. has pointed out, such an approach is also beneficial when fuzzy concepts are involved.

The rules of the game need to be updated with a different approach of environmental planning in mind, and therefore the problem makes a good subject to explore from a planning point of view. Exploring this situation can contribute to creating more suitable rules, and therefore facilitating a smart electricity grid.

2.2. Facilitating a smarter game

Wolsink (2012) stated that the current energy supply systems are highly institutionalized, as they are full of socially and culturally defined patterns of thinking as well as regulations and norms. These were not formed with smart grids or decentralized generation in mind, and as Lammers and Hoppe (2019) identified they can be considered outdated.

Integrating distributed energy resources in the grid will bring requirements in terms of safe interconnectedness, whilst providing the services normally provided by large generators at the same time. Collins & Ketter (2014) mention that there are two options to maintain grid stability during the integration of distributed energy resources: large amounts of energy storage or a change in demand response to match the patterns of consumption to availability of renewables. The latter would turn retail customers from passive consumers to more active participants. Distributed energy resource units in the residential distribution network, such as rooftop solar PV, micro combined heat and power, battery storage systems and electric vehicles, are appearing more and more. This has resulted in a more uncertain consumption pattern of consumers. At the same time, the power demand reaches a peak during a short period. Maintaining a substantial amount of network and generation capacity to match such peaks and following fluctuations is economically not viable (Nizami & Hossain, 2017). This can be seen as a possible barrier for the implementation of smart grids of an institutional kind. Later in this thesis, in section 3.5., there will be an elaboration on institutions. The role of economic viability in the implementation of smart grids reappears in several chapters of this thesis.

Nonetheless, smart grid solutions are mentioned as a possible way to solve the problematic situation. Naus et al. (2014) state that a partial shift toward a more distributed configuration can already be witnessed. They claim that this systematic shift towards a more decentralised and sustainable future can be seen as a possible pathway in the energy transition. Opportunities for an acceleration of this transition seem to arise with the advent of smart grids and smart meters. The European Commission (2011, p. 2) has even gone as far as calling smart grids "the backbone of the future decarbonized power system". Smart meters form a component of smart grids that enable the detailed monitoring of energy production and consumption of households. The two-way exchange flows of energy and information between households and energy providers can also be monitored (Naus et al., 2014). However, smart grids seem to be in an early stage of development. De Beaufort et al. (2017) claim that in order to check who has produced energy gains and to achieve transparent energy efficiency services compensations, a particular kind of registry is needed. This registry would have to monitor and archive in order to make predictive maintenance of equipment possible.

The development of smart grid infrastructures and the growth of the deployment of distributed energy production make it crucial to rethink the current electrical energy system and the 'rules of the game'. This requires obtaining knowledge on how the current system operates. To explore the situation and challenges regarding the non-technical side of a smart grid, it is important to gather knowledge from those involved in operating the grid and the developments the grid is facing.

2.3. Relevance for academics and planning practice

The relevance of this study for society has been explained earlier in this chapter. To summarize, the fluctuating electricity supply of renewables limits structural development for renewable energy, and given the growing global electricity demand and the ambitions of governments to have a larger share of electricity from renewables this can be seen as a growing problem. Ideally, large-scale energy storage projects and demand response would greatly contribute to solving this problem.

There is, however, little knowledge regarding the institutional factors that hinder and facilitate decision-making in smart grid projects. Lammers and Hoppe (2019) studied local smart grid projects at city district level in the Netherlands to reduce this knowledge gap. They recommend more research on the creation and adequate orchestration institutional conditions for smart grid projects. Researching these institutional conditions also means that the fuzzy character of the concept 'smart grid' should be taken into account. Research in general can contribute to policies and facilitate the decisions of policy-makers in particular (Kothari, 2004). Naus et al. (2014) claim that more research is required on the various forms of centralised-decentralised collaboration, and thus for this collaboration to come together in a smart energy system.

Therefore, this study provides insights on institutional conditions, or rules of the game, that obstruct the realization of smart grid projects. Special attention will be paid to the collaboration of stakeholders against a background of increasingly distributed generation and electrical energy storage.

Another knowledge gap that can be identified in scientific literature is the gap between the topics of energy storage and blockchain technology. A possible explanation for this could be that conducting research on the topics of blockchain, the energy market, the energy transition and energy storage covers a wide variety of disciplines. Blockchain technology itself offers possibilities to facilitate local energy storage by making peer to peer energy transactions possible in an efficient and transparent way. Recent pilot projects in the energy sector illustrate this potential. Therefore, this research also offers insights on the topic of blockchain technology and its applicability in a smart energy system.

Besides building on identified knowledge gaps and combining academic topics, this research also aims at contributing to the world of planning practice, specifically in the area of smart grid development. Ideally, the findings would be useful for policy makers, grid operators, (renewable) energy suppliers and possibly other stakeholders that are interested in the development of smart grids, and with it solving the problem of a fluctuating renewable energy output. As the research itself is quite explorative, it is difficult to say to what degree the findings will be useful and what effect they will have on smart grid development. At the very least this research will propose recommendations for making the rules of the game up-to-date.

2.4. Research questions

Chapter 1 has introduced the troubling situation that the Netherlands currently is in and what stands in the way of successfully reaching the Dutch goals of renewables: fluctuations of the renewable energy supply and the lack of energy storage capabilities. This situation is of course not limited to the Netherlands alone but affects countries across the globe. The Netherlands specifically makes an interesting country to investigate as it struggles with the realizations of renewable energy targets. It has also become clear that smart grid solutions are seen as developments with a high potential to contribute to solving this problem. Smart grid development is made difficult by outdated or unsuitable institutional conditions in the Netherlands. These conditions have already been studied by Lammers and Hoppe (2019), but more research on what institutional conditions require adjustment can still be done.

In the development of these conditions several things need to be taken into account. First of all, the fuzzy character of certain concepts has to be dealt with. A smart energy system, regardless of the exact form of this system, is likely to bring consequences for various stakeholders and their roles, including end users that have concerns regarding safety and privacy. Therefore the current electricity grid of the Netherlands will be investigated. How is it operated, and to what extent is it already ‘smart’? The concept ‘smart grid’ will need to be explored before answering the latter question.

Looking into the current grid and smart grids should provide a basis of the expected developments the grid will face. These developments take place in the context of the energy transition. The energy transition toward renewables has to be taken into account to place the current situation of the Dutch electricity grid and its expected developments in the right context. As this thesis focuses on the institutional conditions it also makes sense to look at transition theory. Institutional conditions are considered to be the rules of the game in society and transitions are considered a transformation process that fundamentally changes society. This transformation happens on several levels of social organisation. Therefore transition theory has an important role in this thesis.

Another important topic to explore is energy storage. Energy storage can significantly contribute to the problem of a fluctuating energy supply, but how is this to be implemented in the energy system?

The topics above should make clear what the game of the ‘rules of the game’ is and how the game will change. To look at the rules, it also needs to be clear what an institution is and how it forms an institutional design.

This all results in the following (sub) research questions divided per category:

Dutch electricity grid and smart grids:

- *How can the current electricity grid of the Netherlands be conceptualized and how is it operated?*
- *When can an electricity grid be considered a smart grid?*
- *To what extent can the current electricity grid of the Netherlands be considered smart?*
- *What changes need to be made to facilitate a growing share of renewables in a smart grid and what consequences do these bring?*

Transition theory:

- *How can the developments of the grid be seen from a transition theory perspective?*

Energy storage:

- *What is the state of the institutional design for energy storage?*

Blockchain

- *How can the fuzzy character of blockchain be unraveled and how could the technology contribute to the smart grid?*
-

Answering the sub questions above should provide insights regarding the topics above. Eventually they lead up to the main research question of this thesis:

Which institutional conditions of the Dutch electricity grid form a barrier for implementing smart grids in the Netherlands?

Chapter 3 – Theoretical framework

Chapter 3 forms the theoretical framework by performing a literature on international academic literature. The goal of this chapter is to gain a better understanding of the objective, resulting in a conceptual model. The conceptual model provides insight on the rules of the game based on theory and is used as a tool for further research.

Most importantly this chapter connects transition theory to several important topics and institutional conditions. Transition theory is highly relevant as the transition from the current electricity grid towards a smart electricity grid is key. This transition also takes place in the context of the energy transition. Connecting transition theory to the rules of the game in society also makes sense as a transition can be seen as the transformation process that fundamentally changes society and takes place on different levels of social organisation.

The literature review on the Dutch grid, electricity storage, electricity storage and smart grids is supplemented with findings from a desk research. The reason for this is that these topics are highly relevant for this thesis and not all information required to answer certain research questions can be gathered from academic literature alone. In the end the conceptual model connects transition theory to the Dutch grid, electricity storage, smart grids and institutions.

This chapter starts with a section that elaborates on the evolution and operation of the Dutch electricity grid. This is followed by energy transition and transition theory, electricity storage, smart grids and institutions. In 3.6. the conceptual model is presented.

3.1. The Dutch electricity grid

This section will first briefly discuss the evolution of the Dutch electricity grid. Then an elaboration will take place on the current state of the Dutch electricity grid. The section finishes with an exploration of possible pathways towards a system suitable for distributed renewable energy sources and peer-to-peer transactions.

3.1.1. Development of the Dutch electricity grid

The electricity grid transports electrical energy from an international scale level to a local scale level. To make this possible, all electricity grids on the various scale levels are interconnected. The grid that is formed has two functions: transportation and distribution.
The transportation function can in practice be found on the international and national scale levels. It is formed by the so-called 'linking grid' and 'transport grid'. The former operates on an international level and is linked to neighbouring grids. The linking grid is also connected to power plants that produce more than 500 MVA. The latter forms a step between the linking grid and the distribution grids and provides the electricity supply on a provincial level. Power plants that produce 10 to 500 MVA are connected to the transport grid, as well as wind parks and large industrial clients.

The distribution takes place in regional and local distribution grids. The regional distribution grid is connected to large decentralized electricity producers and large industrial clients (smaller than 10

MVA). The local distribution grid distributes the electricity to the small end users. Because of the rise of distributed generation, often renewable, the amount of producers connected to this local grid is rising (Van Oirsouw, 2012).

Figure 7 visualizes the different grids that together form the Dutch electricity grid. The linking grid is shown in red, the transport grid in orange, the regional distribution grid in green and the local distribution grid in blue.

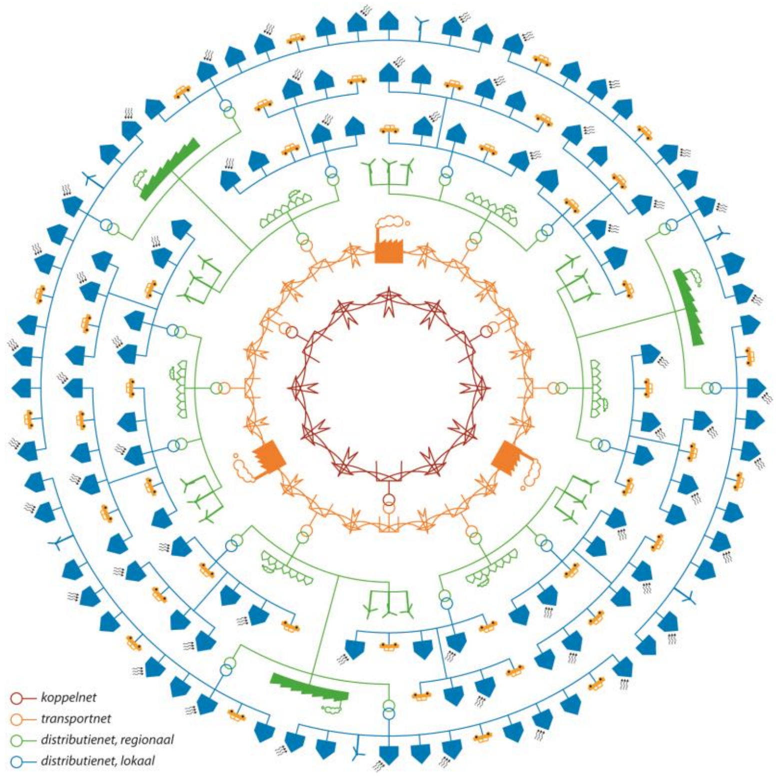

Figure 7: The electricity grid, divided by functions (Van Oirsouw, 2012).

Figure 7 illustrates that the different grids are strictly separated and organized in a hierarchically. The electricity grid originates from the late 18th century, where large production facilities were established for distributing power to end users in a hierarchical fashion. Resources used for production have over time switched from coal to oil and gas. Typically, the energy sector has been characterized by being a state-owned industry (Pagani and Aiello, 2016). In the last couple of decades a trend of moving away from state-ownership can be identified. Since the 1990's, this trend has also taken place in the Netherlands (Naus et al., 2014).

In 2004 semi-governmental utilities officially transformed into private energy providers, with the grid remaining semi-governmental. A remarkable trend is the growth of local renewable energy initiatives since 2011, aimed at distributing electricity amongst members instead of giving it to the grid for a financial return. (Naus et al., 2014).

Verbong and Geels (2007) describe this transformation into private energy providers as a shift towards a more market-based system. Currently, the system is still under pressure from the changes that the liberalization process introduced. This pressure is influenced by sunk costs from investments in technology and facilities, but also by passive consumers. Verbong and Geels (2007) also claim that there are important roles for social networks, belief systems and social capabilities in consumer inertia. To some degree one could conclude the claim by Verbong and Geels (2007) is outdated, as local renewable energy businesses and cooperatives show a change in consumer behaviour. Energy providers, such as Greenchoice, seem to anticipate on the consumer's inertia by taking on a facilitating role in local initiatives (Naus et al., 2014).

Naus et al. (2015) stress the importance of new forms of relationships that a decentralized electricity grid would bring. For households, this would result in more control over energy production, generation and distribution. At the same time, households would gain more options regarding control over data of electricity usage by others. Eventually, distributed electricity production would lead to new sustainable incentives: households gain knowledge and experience regarding renewable energy. Naus et al. (2015) conclude that new forms of governance are required to enable innovative practices to emerge and spread, as the current governance form is rather constraining.

3.1.2. Operating the grid

Grid operators are responsible for installing, operating and maintaining the electricity grid. Tennet is the national operator of the high voltage grid (transport and linking grids), whilst low voltage grids are in the hands of regional grid operators. The regional operators also make sure customers are connected to the grid (Tennet, 2018a). Because the grid is in the hands of the national and regional operators, a part of the network always needs to be managed by one of the licensed operators. Exceptions could be made by the Authority of Consumers and Markets (ACM) for small, secluded networks (ACM, 2018a).

Figure 8: The Dutch regional network operators (Energieleveranciers.nl, 2018)

Figure 8 shows the regional network operators in the Netherlands and it can be seen that Enexis, Liander and Stedin cover the largest parts of the country. The regional network operators make sure customers are connected to the grid, but also face the rising amount of distributed generators. These distributed generators require a connection to the lower voltage grids.

As Tennet is the operator on the highest scale level, Tennet is also responsible for importing and exporting electricity, balancing supply and demand and securing safety and reliability (Tennet, 2018a). Tennet also is obligated to connect all new generation capacity to the transmission grid, regardless of the available transmission capacity. The Dutch Ministry of Economic Affairs considered this a necessity to ensure a quick connection to the grid for new market entrants, rather than having to wait until enough transmission capacity is available. The risk of congestion on the transmission network has increased because of this policy, especially since the construction of power plants in the Eemshaven and Maasvlakte areas (Van Blijswijk and De Vries, 2012).

The energy networks of the countries in the European Union are connected to each other. Energy companies buy and sell large volumes of electricity on the European wholesale market. The retail market is the place where energy suppliers sell electricity to consumers and small businesses. As the wholesale market is on an European level, balancing demand and supply can also be seen as something to be managed on a European level (ACM, 2018b). This also means that countries depend on each other for a secure supply of electricity.

The high voltage grid and the grids of regional distributors are connected at substations. At these substations the conversion from high to low voltage takes place, making sure it can be used by households, businesses and organizations (Tennet, 2018b). As of 2017, there were 15 substations in the Netherlands. (Tennet, 2017c). According to the NL Times (2018) the electricity grid in the Groningen and Northern Drenthe area, located in the Northeast of the Netherlands, is dealing with some capacity issues. These issues have resulted in a situation where the grid cannot process the electricity generated by new solar parks. Many requests for solar parks keep coming in for distributor Enexis in the area, as the relatively low-priced land is considered suitable for solar park projects. According to Enexis, upgrading the capacity of the grid is not possible on the short term. This means that until the capacity is upgraded such projects will have to be realized elsewhere.

3.2. Energy transition and transition theory

This section will introduce the energy transition and transition theory. A transition can be seen as a transformation process that fundamentally changes society and takes place on different levels of social organisation. The transition from the current electricity grid towards a smart electricity grid takes place in the context of the energy transition from fossil fuels to renewable energy sources. It is therefore essential to take a deeper look into transitions and transition theory. What does this mean in the world of energy (and specifically electricity) networks? Transition theory and the definition of a transition will be discussed, as well as the context of the energy transition and the role of the government.

3.2.1. Transition theory

According to Rotmans et al. (2001), a transition is usually described as transformation process that changes society in a fundamental way over at least one generation. Rotmans et al. (2001) link a transition to a period of 25 to 50 years. It is commonly called a gradual, continuous process and can have large differences in time and scale. Van den Brugge et al. (2005, p. 165-166) describe a transition as a *"process of co-evolution of markets, networks, institutions, technologies, policies, individual behaviour and autonomous trends from one relatively stable system state to another".* This process is usually illustrated in an S-shaped curve, as can be seen in figure 5. The simplified curve mainly shows that development, sometimes described as rapid, takes place between two equilibrium states. Rotmans et al. (2001) describe four different phases of a transition. Firstly, there is a pre-development phase. During this phase, the status quo does not change and indicators for social development cannot be distinguished. After the pre-development phase comes the take-off phase. The process of change starts here and the state of the system starts shifting. After the transition has taken off, a phase of acceleration arrives. Visible structural changes take place here and react to each other. Eventually, the stabilization phase is reached during which the speed of change decreases and a new dynamic equilibrium is reached.

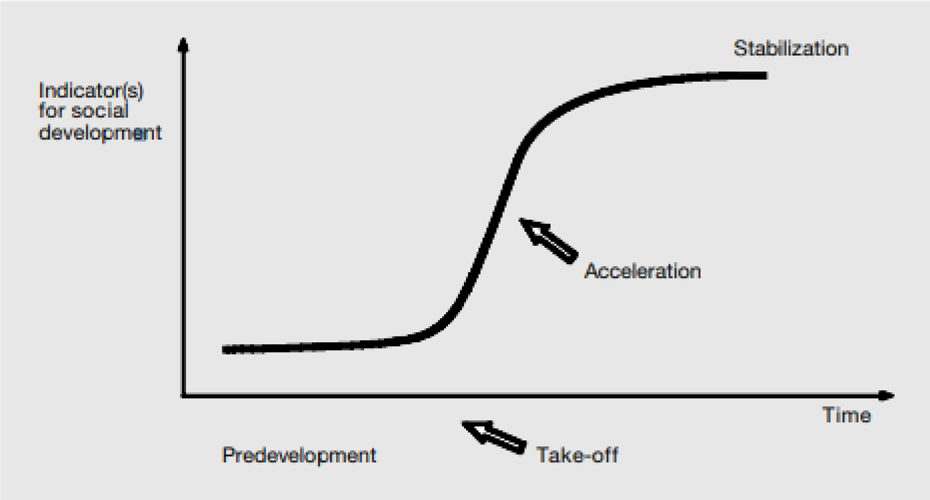

Figure 5: the four phases of transition (Rotmans et al., 2001).

Rotmans et al. (2001) claim that transitions contain an important role for governments, as they can influence, but never control, the various development paths. As a transition changes society, changes take place in different domains and therefore in different areas, such as technology, economy, behaviour and culture. Independent developments take place, but also reinforce each other. Multiple causality and co-evolution are therefore an inherent part of a transition. Rotmans and Avelino (2009) add that transitions structurally transform a societal system in a non-linear process.

The fundamental changes that take place during a transition happen on three scale levels of social organisation (figure 6): macro, meso and micro (Rotmans et al., 2001). These scale levels are described as 'functional scales' by Van der Brugge et al. (2005) The macro level is formed by large institutions or organizations such as a nation or a federation of states. Examples of a developments in the macro energy sector were the discovery of a large gas field in the Netherlands and the decline of profitability of Dutch coal mines because of cheaper coal from North America.
The meso level consists of networks, communities and organizations. On the meso level, the Dutch government established a state gas company for gas distribution. A different company was created for supplying the gas, the Gasunie, with shares being owned by both the state and oil companies. This public-private partnership was important for the transition from a reliance on coal to a reliance on gas and oil.
The micro level is formed by individuals and individual actors such as companies and environmental movements. A development on the micro level was the growing need for efficient and affordable ways to heat up households and to provide them with warm water.

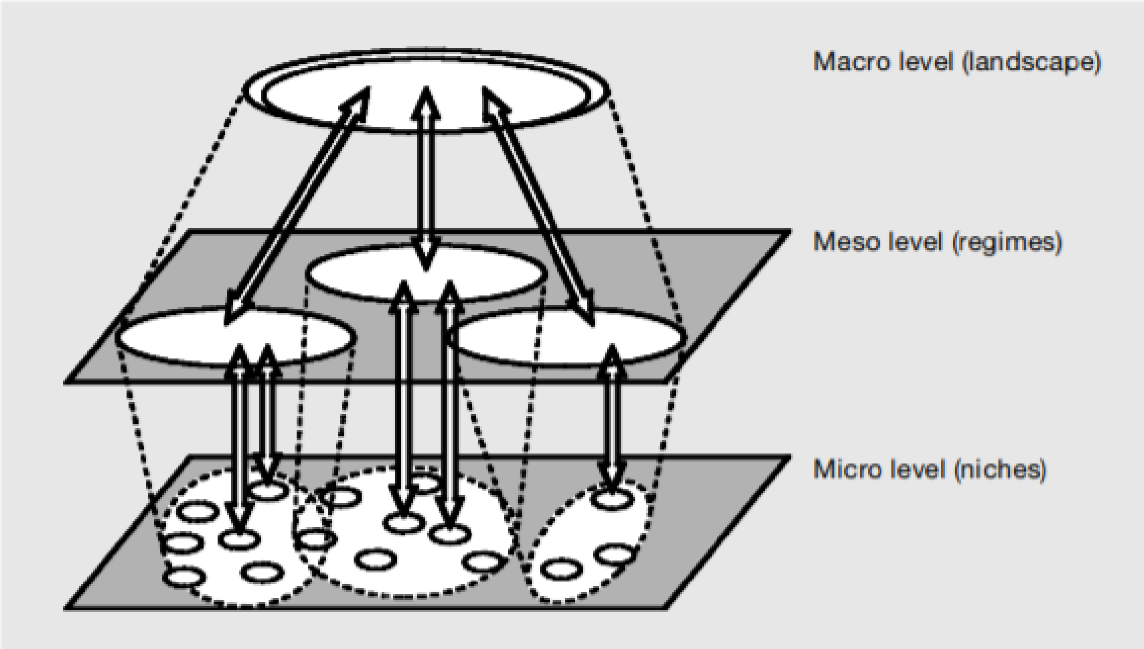

Figure 6: The multi-level perspective (Rotmans et al., 2001).

The multi-phased development happens within the levels of the multi-level perspective, and the two concepts can therefore be linked to each other. In the pre-development phase the regime plays an obstructing role as the regime wants to maintain social norms and beliefs. When a modulation of developments is happening at the micro and macro levels, the take-off phase is reached. Innovations at the micro level are stimulated by changes at the macro level. During the switch from the pre-development to the take-off phase there will be a merging of different ideas and perspectives into one, more or less consistent pattern. In the acceleration phase the regime will have an enabling role by using knowledge, capital and technology. Pressures from the micro and macro levels change the regime and dominant practices change because of developments on the three levels. The new regime will start obstructing new developments in the stabilization phase and acceleration will slow down. As the S-curve from figure 5 shows, a new equilibrium is reached in this phase. Of course this does not mean the end, as a new transition could rise from the new equilibrium (Van der Brugge et al., 2005).

3.2.2. Energy transition: the context

The transition that is to be made towards a reliance on renewable energy is not the first transition in the energy sector. A very important energy transition in the Netherlands took place in the form a change from a reliance on coal to a reliance on natural gas and oil for energy production (Rotmans et al., 2001). This transition took place in a relatively quick and smooth way, in which the government played a crucial role. There was, however, a long pre-development phase that started in the 1920s when useful applications for gas were invented. Over the span of several decades, the Dutch government managed to create a set of clear goals and distributed information to the public effectively. Support from the public was gained when the benefits of gas became clear to many households in poor conditions regarding heating and cooking. The transition was considered complete in the 1960s.

As a transition takes place in an uncertain and complex context, the context needs to be taken into account in managing a transition. Typically, this is done by public decision-makers and private actors. The uncertain, complex context calls for a set of objectives in an exploratory way. Other important features mentioned by Rotmans et al. (2001) are a focus on learning, a large playing field, a large variety of options and system innovation as well as system improvement. Furthermore, Rotmans et al. (2001) identify a multi-level, multi-domain and multi-actor orientations. This situation is in line with the conclusion of their article: not one actor can steer a transition, but all social actors look at the government to take the lead. To do this, the government has an large set of instruments. A form of participation is proposed where new, niche-players become involved as they may play an important role. According to Negro et al. (2012), there is a strong preference amongst Dutch policy makers to keep the existing lobby networks in place. Incumbent firms are stimulated to innovate to reach sustainable goals. To work on visions and create realistic expectations for a developing technology, new entrants could be included more to formulate specific needs. That appears to be difficult.

Incumbent technologies, institutions and actors are very powerful and well organized in the energy sector. They could attempt to block the development of a certain emerging innovation because of their interest in the current system. Policy makers in the Netherlands tend to give them a large influence in the designing process of policies regarding renewable energy (Negro et al., 2012). Kern and Smith (2008) described this as a situation dominated by regime actors, where there is little open space available for new practices that could contribute to system innovations. This makes achieving structural change difficult and the optimization of the current grid more likely. They also mention that niches are involved in policy planning, but only those who fit into the existing regime as they will not demand large changes is the socio-technical system. Following the multi-level perspective, it seems that structural change is unlikely to happen: actors on the niche level have too little influence to have an effect on regime level. Especially without favorable developments on the landscape level, a full system innovation is unlikely to happen (Kern and Smith, 2008). However, Verbong and Geels (2010) claim that public pressure to shift towards renewable electricity production is rising. Pressure from the landscape level has resulted in policy efforts aimed at creating a bigger share of renewable energy. Wolsink (2012) sees these policies as generic and full of 'buzz words', with no attention to or understanding of the need for institutional change and social acceptance issues. This neglect resulted in slow development of developing and applying renewable energy efforts. Wolsink (2012) states that this leads to a danger of overlooking promising solutions smart grid development.

Biomass

Biomass is a collective term for all plant-based organic material. Through combustion, which mostly takes place in coal-combustion plants, energy is released. The combustion of biomass is considered a sustainable source of energy because harvested biomass is compensated by planting new biomass. The CO_2 released during the combustion is absorbed by the newly planted biomass. The time lag between the release of CO_2 during combustion and its absorption makes it questionable how sustainable this process actually is (McKendry, 2002).

The fact that biomass is the largest source of renewable electricity in the Netherlands illustrates the situation. Companies do not need to make large changes to their installations as biomass is processed at coal combustion plants. Therefore it is a cheap short-term solution (Negro et al., 2012). Verbong and Geels (2006) agree that biomass is feasible as it is closest to the existing regime in functional and technical aspects. Wind power, for example, has resulted in more resistance. Electricity generating companies tend to argue that wind turbines produce a relatively small amount of electricity. The vast Dutch national gas supply, bird killing, horizon pollution and operational problems are mentioned as other arguments (Negro et al., 2012). Entrepreneurs of new technologies often miss the capability to cooperate and lobby together for their technology and to form realistic expectations. Instead, they compete with each other at an early stage. This results in a situation where they have limited influence in the sector with regards to policymaking, obtaining resources and the creation of a niche market (Negro et al., 2012).

According to Pagani and Aiello (2016), the energy transition will change the way traditional power systems have been considered as local energy production and distribution will grow. This means that new players will enter the energy market and that the lower voltage layer of the grid will change into a component with multi-directional energy flows. It requires an enhanced grid. This new, enhanced distribution grid that can facilitate multidirectional flows is described as the 'smart grid'. Pagani and Aiello (2016) add that this is in particular accurate for the lower voltage grids, as the high voltage grid can already be considered as quite smart, with energy management systems, data acquisition and supervisory control. The lower voltage grids are the ones that will have to facilitate distributed generation, a process described as the 'unbundling' of the energy sector by Pagani and Aiello (2016). This unbundling in an extreme form would lead to a free energy market where potentially everyone could produce and sell energy. A situation with many distributed producers and local energy exchange is considered desirable, but cannot be implemented without the appropriate infrastructure and affordable options for energy storage (Pagani and Aiello, 2016).

3.2.3. Transition pathways

In 2.2.1. and 2.2.2. it has become clear that incumbent actors within the current regime have a large influence on policymaking. Verbong and Geels (2010) state that the market-based configuration led to a short-term and cost-minimization orientation of utilities. Policy makers and regime actors trust that transforming the grid into a smart grid can solve the problematic situation of the electricity grid. The direction this transformation should take however is unclear. Verbong and Geels (2010) established several different pathways that the electricity system could take.

1. Transformation

Pressures from the landscape level encourage regime actors to implement gradual changes. Innovations from the niche level are not used in this transformation pathway. Pressures from the landscape level could for example take place in the form of changing consumer preferences and stricter regulations. A new regime is formed through gradual change and cumulative reconfigurations. Radical innovations are limited to the niche level.

2. Reconfiguration

Both pressure from the landscape level and developed innovations from the niche level result in the adoption of niche-innovations by regime actors. The niche-innovation or innovations are added to the system or replace certain components. By doing this, a gradual reconfiguration of the grid is achieved. The difference between the reconfiguration pathway and the transformation pathway is that the reconfiguration pathway results in changes in the architecture of the grid by cumulative adoption of new components. The reconfiguration pathway is one where the emphasis lies on interaction between actors from both the regime and the niche level. Together they develop new components and technology applications.

3. Technical substitution

Pressures from the landscape level result in windows of opportunity for innovations from the niche level as the pressures form a problem for regime actors. A diffusion of developed innovations could take the form of a so-called niche-accumulation, with the new technologies gaining entrance to bigger markets. Eventually, the existing regime is replaced: the niche actors compete with the incumbent actors from the existing regime.

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4. De-alignment and re-alignment

Regime actors face large problems because of changes on the landscape level. The situation becomes so problematic that regime actors start losing faith in the future of their system. This destabilization creates a period of uncertainty. During this period, niche-innovations develop and experiments are conducted. A major restructuring of the grid takes place when an innovation effort becomes dominant. The existing regime will face new practices, actors and beliefs.

Of the pathways mentioned above, Verbong and Geels (2010) see the technical substitution as unrealistic for the electricity grid. The reason for this is that a full replacement of the grid is extremely unlikely.

It is obvious that updating the electricity grid requires large investments. Grid operators are facing those large investments to establish a grid suitable for reaching environmental goals and to possibly ensure multidirectional flows of electricity. Agrell et al. (2013) state that these infrastructure investments will very likely be noticeable for end users. Pagani and Aiello (2016) investigated the costs of deploying the new electrical infrastructure. They concluded that, based on their samples from the Northern Netherlands, the investment in cabling costs about 25% of the value of the currently installed cables. The investment and implementation of the smart grid of course provides benefits on its own, although the returns are difficult to express in monetary terms. Benefits include the reduction of losses and increased robustness. Furthermore, Pagani and Aiello (2016) recommend using a mix of strategies for upgrading the distribution grid. They expect this would yield better results, as using one strategy will not lead to the same benefits in every section of the grid. A dynamic approach with multiple strategies for improving connectivity or performance capacity is what they see as most beneficial for the grid. In practice, this could take the form of removing nodes in one place and improving the connecting wires in another (Pagani and Aiello, 2016). It can be concluded that Pagani and Aiello (2016) agree with Verbong and Geels (2010) that the technical substitution pathway is neither realistic nor the most beneficial for the grid.

In 3.2. it has become clear that regime actors are considered to be dominant in the energy sector, and that niche actors only have an influence on policymaking when they fit into the existing regime. It also seems that pressure from the landscape level to increase the efforts to stimulate renewable electricity is rising, leading to new policy efforts. This means that a transformation (1) or reconfiguration (2) of the grid appears to be the most likely to be realized. Although the pathways are focused on the application of innovations and therefore put an emphasis on a technical upgrade of the grid, they are the result of developments on the different levels of social organization. Therefore the pathways illustrate the connection between transition theory and the technical upgrade of the grid infrastructure.

So far in this chapter, the Dutch electricity grid, the energy transition and transition theory have been discussed. The transition towards a smart grid with electricity from renewable sources enlarges the need for flexibility as the output of electricity will become increasingly fluctuating. Storing energy during periods of overproduction and using stored energy during periods of scarcity could fill the need for flexibility. Energy storage could take place in different forms, with different methods and on different scale levels. The next section will therefore elaborate on energy storage, specifically in the form of electricity.

3.3. Electricity storage

This section focusses on the topic of electricity storage. The need for electricity storage options will be discussed, as well as potential forms of storage. Extra emphasis is put on electric vehicles, bringing both options for storage and stress to the electricity grid.

3.3.1. Wanted: storage capacity

In the Dutch Klimaatakkoord (climate agreement), presented on the 29th of June 2019, the increase of flexibility has been named crucial when it comes to connecting renewables to the electricity grid. Storage is one of the options to increase flexibility. Traditionally, power systems maintain a production capacity large enough to deal with peak demands that occur a few hours per year. According to Zakeri and Syri (2015), this could lead to inefficient, non-environmental and oversized power systems. Peak hours constrain the generation capacity and the systems of transmission and distribution. The transmission and distribution systems are designed for one-way operation. To successfully operate during peak hours, these systems must have a large capacity. With the rise of distributed generation, the one-way flow of energy over the transmission and distribution network is no longer a given fact. Zakeri and Syri (2015) state that distributed generation leads to further resource flexibility and dispatches the problem of central generation and large capacity transmission. Therefore, they see distributed generation as a suitable path to reach a larger share of renewable-based electricity.

Electrical energy storage (EES) is seen as an alternative. EES is considered an inherent part of many smart grid schemes, which itself are seen as a big step in reaching sustainable energy systems. Verzijlbergh et al. (2017) state that storage has a key role in an electricity grid based on renewables. Power in low demand time could be stored to be used during peak hours. This way, extra power capacity would be unnecessary. Luo et al. (2015) agree that EES could contribute to solving the problem of unpredictable variations in usage on a daily and seasonal level. Various technologies for converting electrical energy to a storable form and vice versa exist and make it possible to use stored electrical energy when needed. Most technologies, however, are not believed to be cost-effective or mature enough for widespread application (Luo et al., 2015). On the other hand, Zakeri and Syri (2015) claim that EES could decrease the risk of an overloaded transmission and distribution network and that an oversized construction of power capacity is no longer required. This way, a reduction in grid management and reliability service costs could be made possible. They also draw the important conclusion that cost estimations of EES systems are inconsistent and rely on assumptions. A lot of the cost data is site-specific. As the size is scaled, consistency among different sources of data is further decreased.

3.3.2. Scale levels of storage

Pop et al. (2018) state that there is a lack of grid-scale energy storage capacity. Given the situation where smart metering devices are being installed as the first step of smart grid development and renewable energy generation in a distributed, decentralized way, they claim that electrical energy needs to be used as it is generated. Large-scale electricity storage could contribute to provide grid stability and flexibility.

Various technologies for electricity storage have been created. These technologies come with different properties regarding energy capacity, power capacity and response time. Verzijlbergh et al. (2017) therefore state that no single technology is superior for all intended applications. Considering the time scales ranging from microseconds, in case of quick responses, to months, in case of seasonal storage, it is likely that different storage technologies require to be used in a smart grid. In addition to this, the Klimaatakkoord of 2019 states that for long-term flexibility it is required to have a mix of sources of flexibility, including electricity storage.

Poullikkas (2013) made a comparison between various existing large scale EES techniques. One of the conclusion was that all of the existing techniques, besides site-specific techniques, are perfectly capable of quickly providing electricity towards the grid. The capacity, efficiency, and costs vary between the different techniques, and per technique a range of costs could be identified as well. As Zakeri and Syri (2015) noticed a questionable consistency in costs as well, it can be concluded that a site-specific case study is required to decide which large-scale electricity storage technique is most attractive to use. According to Verzijlbergh et al. (2017), the most economically viable and widely used form of large-scale storage is pumped hydro storage, suitable for daily fluctuations. This is not a problem solver for the Netherlands, given the few differences in height in the country. Verzijlbergh et al. (2017) also mention that the need for seasonal storage in a pan-European electricity grid may be as large as 10% of the annual electricity use of Europe. All pumped hydro capacity combined in Europe does not meet this large storage requirement.

Another storage method that has gained interest is using hydrogen as an energy resource. Hydrogen gas is a highly abundant and non-toxic renewable fuel that when burned releases water vapour into the environment. Hydrogen also has a very high energy content per weight and burns more quickly than gasoline. It is however a 'secondary' energy source, as it is an energy carrier rather than a source of energy itself. Hydrogen can be stored in a variety of options with different conditions regarding pressure and temperature. In the form of fuel cells it could be used instead of batteries (Niaz et al., 2015). A great part of hydrogen technologies are still in a developing phase and are not yet commercially available (Amirante et al., 2017). However, hydrogen is given an important role in the Klimaatakkoord of 2019. The 'hydrogen program' has been created to develop a hydrogen system that should contain important functions in a CO2-free energy system (Rijksoverheid, 2019).

The economic feasibility of EES in general is questioned by Ekman and Jensen (2010). They state that this depends on factors such as the power market size, the link to neighbouring markets and the amount of renewable energy sources in the area. Large scale EES gives the highest annual revenues when it is applied to the market for fast reserves. Ekman and Jensen (2010) mention as well that for large scale EES to be profitable the share of renewables, especially electricity generation by wind turbines, and the demand for regulation needs to grow. For large-scale electricity storage to be widely implemented, it seems that either the share of renewables needs to grow or the average costs of the techniques need to decrease. Verzijlbergh et al. (2017) even state that the costs of all large-scale electricity storage are beyond the benefits that they bring and that it remains unclear what large scale storage technologies could cope with long periods where there is a low output of renewables.

Storage techniques on a smaller scale, such as on a household or neighbourhood level, also exist and are being put more and more into practice. Verzijlbergh et al. (2017) mention battery storage as an option that is largely compatible with a more decentralized electricity grid. Developments regarding battery storage are numerous, but the costs, lifespan and performance of commercially available batteries will have to be enhanced if they are to play a key role in a smart grid.

Nonetheless, residential energy storage systems increase the self-consumption of produced electricity and are on some occasions backed up by governmental financial support (Müller and Welpe, 2018). Costs of residential EES, like the storage on larger scales, remain high. A shared or aggregated use of EES on a community or neighbourhood level offers a more feasible option. Müller and Welpe (2018) investigated several EES storage projects on the neighbourhood level in Germany and Australia. They concluded that no model for shared or aggregated EES exists and that such a system faces regulatory barriers, and recommend that policymakers make regulatory adjustments. Otherwise, household and neighbourhood EES is likely to remain a niche. This situation calls for studying the institutional barriers that keep policymakers from taking the step to make actual adjustments.

3.3.3. Electric vehicles: batteries on wheels?

Besides large scale and household or neighbourhood level EES, another development offers chances for storage. The Dutch government aims at having 1.000.000 electric vehicles (EV's) on the road in 2025. Recent years have already show a significant increase in EV's in the Netherlands, with 100.000 EV's in the road near the end of 2016. The EV's themselves could have a large contribution to reaching several goals regarding climate and energy. But as most EV's are not used for about 90% of the time and all of them can connect to the electricity grid, their batteries could be used for other purposes as well (Hoogvliet et al., 2017).

Hoogvliet et al. (2017) state that the time EV's are parked and connected to the grid is often longer that necessary for charging the battery. Druitt and Früh (2012) add that this brings extra stress to the grid, but that it also offers possibilities: smart grid technology could control the charging of EV's in a way that benefits both the grid and the EV-owner. This includes the option to deliver electricity back to the grid from the vehicle's battery. Druitt and Früh (2012) also state that their results show that EV's could facilitate the usage of renewable electricity generation in a substantial way. A simulation by Hoogvliet et al. (2017) has shown that this could lead to monetary benefits ranging from €120 to €750 per EV per year, depending on the EV and its user. They also conclude that the market for regulating and reserve power (RRP) is the most suitable for EV's, as it is used to maintain grid balance in the control area of the operator and has suitable dispatch periods and availability requirements. Hoogvliet et al. (2017) do add that implementation is difficult because of non-existent required supporting infrastructure and services.

There are positive conclusions regarding the benefits of connecting EV's to the grid. Besides monetary benefits they can improve grid conditions and flexibility. Ekman and Jensen (2010) even argue that vehicle-to-grid is seen as a necessary element if a high share of renewable wind energy, of around 50% or more, is to be reached. Connecting EV's to the grid and vehicle-to-grid technology however do not exclusively include promising features. Eising et al. (2014) mention that a vehicle-to-grid connection and smart grids are promising technologies, but bring risks as they are not yet available on a large scale and therefore do not offer a supporting infrastructure. The diffusion of EV's could even have negative effect for the functioning of the current grid on the short term. The relatively large amount of early adopters of EV's in densely populated areas, for example, brings stress to the current grid. Uneven distribution could increase risks for grid reliability and functionality. Eising et al. (2014) even stated that the adoption of EV's is 'outpacing' the implementation of smart grids. Recharging data shows that EV's are mostly being charged during already existing peak demands. An article by NOS (2018b) illustrates this risk by claiming there will be a shortage of charging stations for EV's in the winter of 2018-2019, as the EV charging infrastructure can not deal with the fast growing amount of EV's. The problem mentioned by Eising et al. (2014) is one that could be solved. Risks can be reduced by solutions in the form of investments in the electricity grid, vehicle-to-grid and smart grid technology and incentives aimed at changing the behavior of consumers.

Using EV's as batteries on wheels seems to have the potential. The scale at which this could take place however is unclear. Further research is required to gain insights regarding individual or aggregated usage of the batteries of EV's.

3.4. Smart Grids

The following pages are about the concept 'smart grid'. The definition of a smart grid is discussed as well as expected changes to the electricity grid and certain views on smart grids.

3.4.1. Making the grid smart

Smart grids are expected to provide means for electricity consumption monitoring and to develop residential power generators into sites that are suitable for distributed energy trading. As such, it is important to provide a secure energy trading infrastructure with capabilities of putting into effect contracts between traders whilst preserving identity privacy (Aitzhan & Svetinovic, 2018). The name 'smart grid' is based on the idea that information and communication technologies (ICT's) are introduced to the current grid, adding 'intelligence'. According to Verbong et al. (2013), the advantages of such a grid include the improvement of both the physical and economic operation of the electricity system by making it more robust and sustainable, improved efficiency by reducing losses and economic advantages for all stakeholders. The challenge of 'making the grid smart' has been taken up by the USA, the EU and emerging economies like China. R&D programs have been set up and smart grids have been, and are being, tested in practice. However, the visions on the preferred development path towards the future electricity system differ greatly, ranging from a European super grid to local, loosely linked microgrids (Verbong et al., 2013). Obinna et al. (2017) state that the main goal of smart grids is to improve the balance of electricity supply and demand.

Güngör et al. (2011) argue that the hierarchal, centrally controlled energy grid of the 20th century does not fit the needs of the 21st century. The concept of smart grids has emerged from this issue, and is described by Güngör et al. (2011, p. 529) in the following way:

"The smart grid can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability, and so on. While current power systems are based on a solid information and communication infrastructure, the new smart grid needs a different and much more complex one, as its dimension is much larger."

Pop et al. (2018) claim that smart grid architecture increases the flexibility and capacity of the network. The more complex information and communication infrastructure Güngör et al. (2011) describe reappears in the description of a smart energy grid by Naus et al. (2014). They state that within the energy system service providers and resident continuously create and re-create *"mutual relationships of power, autonomy and dependence"* (p. 439). Especially smart grids produce, besides energy, new or reconfigured social relations. Naus et al. (2014) even go as far as claiming that smart grid practices of householders are given form by their relationships with other consuming and producing actors involved in the smart grid. A conceptual framework which connects information flows, social relations and energy practices in the context of smart grids is visualized in figure 9.

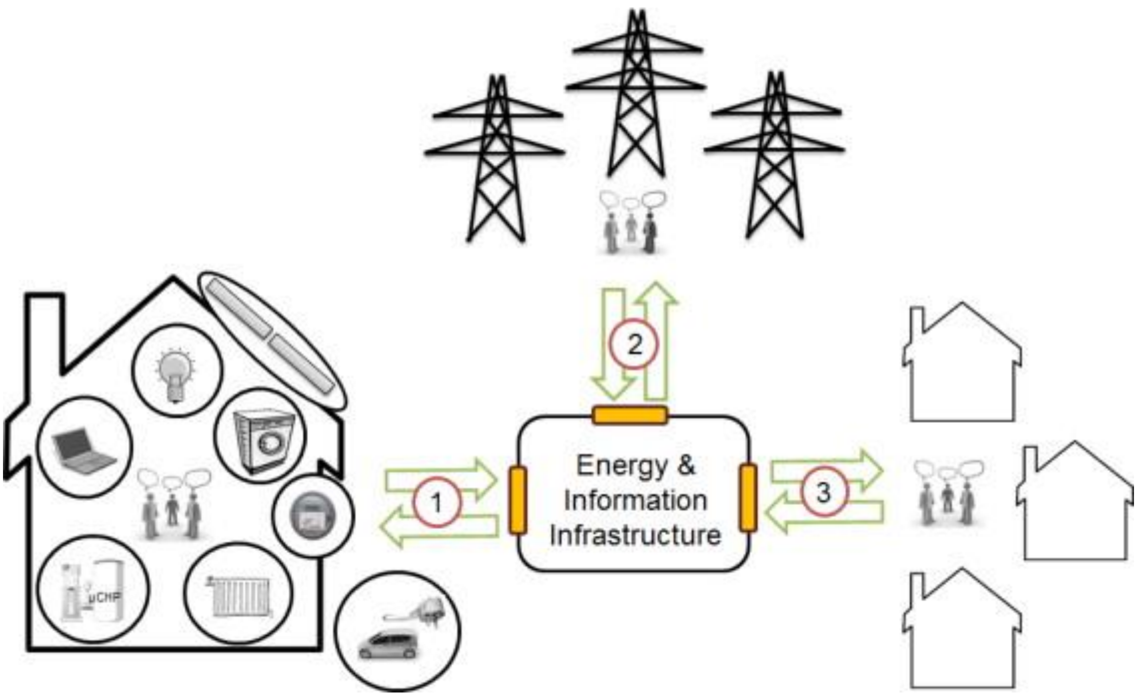

Figure 9: Energy and information flows in smart grids: (1) between household members, (2) between households and service providers, (3) between local and distant households (Naus et al., 2014).

In a period where smart meters were installed in Dutch households (see also 3.4.4), smart grid pilots also took place in the Netherlands. Those pilots experimented with various tariff structures and new appliances. Tariff structures could for example be based on demand, timeslots or on real-time pricing, whilst smart appliances can take the form of remotely switching on/off devices such as washing machines or the charging of EV-batteries (Naus et al., 2015).

A brief comparison between the existing grid and a smart grid is found in table 3, based on a comparison performed by Fang et al. (2012).

Existing Grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Sensors throughout
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

Table 3: A brief comparison between the current gird and a smart grid (based on Fang et al., 2012)

3.4.2. Visions on the smart grid

Wolsink (2012, in Naus et al., 2014) characterizes smart grids as socio-technical networks of both information and energy flows that enable control over practices of distributed generation, consumption, storage and flexible demand. Goulden et al. (2014) also share the view that a smart grid transmits both digital information and energy. They state that the primary purpose of a smart grid is to allow (near) real time consumption and generation data to be transferred between different nodes and to allow possibilities such as remote activation of devices. The facilitation of increased amounts of distributed, often renewable, generation makes the optimization of the balance of generation and consumption possible. This way, a greater efficiency should be able to be reached.

Reaching this goal, Goulden et al. (2014) mention, has the potential to fundamentally alter the social dynamics of the energy system. There are two visions, considered to be positioned on the two poles of a continuum, of a of how smart grids and their potential might be realised (Goulden et al., 2014):

- The centralized, hierarchical paradigm that has formed the energy systems of the last century remains and centralized generators obtain increased monitoring and control of end-user consumption. This vision is described as Centralised Demand Side Management (CDSM).
- The distinction between generators and end-users (individuals or communities) becomes more blurred. End-users become more independent through microgeneration and self-management. This vision is described as Distributed Generation Micro Grids (DGMG)

The two conflicting visions result in a challenge for realization that is at least as much institutional as technical. The challenge depends on consumers being either largely passive and forming a managed demand side, with the agent of change being positioned in the technical realm, or consumers being active managers in the process of consumption and possibly generation. The former means the users of the smart grid will remain essentially dumb, the latter means users being involved in both problem and solution. Goulden et al. (2014) emphasize that whilst both views are very different they are certainly not mutually exclusive. In practice, they are more likely to co-exist. Active 'energy-citizens' could also have different goals when compared to other stakeholders. The most effective smart grid, according to Goulden et al. (2014), is one where intelligence is sourced from both users and devices.

Although Goulden et al. (2014) state that a combination of both visions on the realization of smart grids is likely to be formed, Naus et al. (2014) created two separate scenarios: one of radical centralization and one of radical decentralization. Radical centralization would have an outcome in the form of a, possible transnational, 'supergrid' with a marginal role for households and individuals. Radical decentralization would imply that a set of interconnected micro-grids, who are largely self-governing, will be developed. Those micro-grids would contain groups of households and individuals that become increasingly self-regulating and self-sufficient.

De Beaufort et al. (2017, p. 1) define microgrids as *"a local energy system consisting of distributed energy sources and loads capable of operating in parallel with, or independently from, the main power grid".* To maintain the stability of such a grid, they mention that it is important to connect it with existing power sources distributed by system operators. They also mention that for successful operation it is required that highly frequent monitoring is possible. An important underlying issue for operation is that operators need to be able to trust the full chain of certificates, meaning that data need to be taken into account only once (De Beaufort et al., 2017). This situation puts more emphasis on the installation of smart meters and the handling of cybersecurity and privacy.

This section has elaborated on the concept and visions of a smart grid, but it remains unclear how such a grid should be formed and what institutional conditions stand in the way of smart grid implementation. To gain insight on these conditions and to get closer to an answer to the main research question of this thesis, it is important to discuss institutions and the design of institutions.

3.5. Institutions

According to Alexander (2006), there is one method to affect significant and lasting social change: by changing the people who make up society. Changing people can be done in two ways: by changing individuals and by changing institutions. Institutions can be defined as *"the rules of the game in society"* (Alexander, 2006, p. 2), being networks of norms and technologies that serve collectively valued purposes. Institutions appear in a 'living' form as a cluster of practices and rules to guide appropriate behavior for actors in specific situations. Institutional change happens, and can also be steered. When institutional change happens, it can be seen as institutionalization. When it is made to happen, you can speak of institutional design. As planning involves an intentional transformation of institutions, planning demands institutional design (Alexander, 2006).

To design institutions there has to be a development and of rules, procedures and organizational structures that guide behavior and actions to achieve a desired objective. Alexander (2006) states that there are three 'levels' of institutional design, which are comparable to the levels of social organization from transition theory, introduced in 3.1..
The highest level is applied to full societies or large macro-societal processes and institutions. For planners, the most interesting level is the meso-level. The fields in which professional planners usually work, such as housing, infrastructure, environmental policy or local economic development, are associated with this level of institutional design. This level includes the institutional design of planning and the configuration of implementation and related processes. Networks and organizations are created or transformed and incentives and constraints are put into practice in the form of regulations, laws and resources for implementing policies, programs and plans. The lowest level of institutional design focuses on intra-organizational design of organizations and small semi-formal or informal social units, such as committees, teams and work groups (Alexander, 2006).

The energy system consists not only of interlinked technologies, but also of market actors, network companies and the institutions that govern them. Technologies and institutions are intertwined in a socio-technical system. Most focus in scientific literature has been on the technical challenges that face the energy or electricity grid. Verzijlbergh et al. (2017) state that a more integrated approach is required, looking at both technology and institutions. They describe the institutional sub-system as the *"energy markets, rules and regulations that govern the operation and development of the energy system"* (p. 664). This institutional layer today is based on the process of liberalization that started in the 1990s. Important is the wholesale market, where electricity is traded between producers and consumers, usually represented by retailers. Additional mechanisms and markets are required to handle fluctuating demand and supply in real-time, which is becoming more important given the growing share of renewables. Verzijlbergh et al. (2017) consider the current system as one with a lack of flexibility. This lack of flexibility does not properly match the principles of renewable electricity. Renewables in principle have a marginal cost of zero, and in times of high renewable-based energy production the electricity price will fall. Negative wholesale prices even can occur when the generation exceeds the demand: it is the price that *"large, inflexible generators are willing to pay to avoid temporary shut-downs"* (Verzijlbergh et al., 2017, p. 664). In other words: the institutional design, in this case specifically the rules regarding electricity prices, can have a direct effect on production. This is why Verzijlbergh et al. (2017) call for a more integrated approach.

Verzijlbergh et al. (2017) identified several key institutional areas that specifically require a more integrated approach. These institutional areas can be found in table 2. The call for a more integrated approach fits in with the planning approaches from section 2.1.. In that section it was mentioned that as the complexity of an issue rises the planning approach should become more open and communicative with attention for process-related characteristics.

Institutional area	Requirement
Short-term market design	Reduce the need for greater resource flexibility (possibly by increasing the size of balancing control areas), make the value of resource flexibility more visible in market prices
Coordination between flexible resources and network management	In the international trade, take into account network constraints to achieve a more optimal outcome of the re-dispatch process that solves congestion problems, as this will become more costly with further integration of renewables.
Flexible resources and CO2 policy	Profit maximization or cost minimizing should be less leading in operating the system so that low cost but polluting generators will not keep running. Emissions should be taken into account.
Carbon policy and renewable energy sources-support schemes	The EU Emission Trading System has no shortage of emission rights, resulting in low carbon prices. Funding for renewables reduces the demand for CO2 rights, further decreasing carbon prices. This is beneficial to most polluting generators. As CO2 policy and renewable energy sources-policy cannot be decoupled, they need to be considered in coherence.
International harmonization of energy policies	Renewable electricity in the Netherlands is to be traded like any form of electricity. A surplus of renewable electricity in a neighboring country lowers the wholesale price in the Netherlands, leading to lower revenues for Dutch producers of renewables.
Social acceptance and a renewed perception of the energy system	Fluctuating electricity production will lead to fluctuating prices. A continuous availability of cheap electricity might not be possible in the future. This would require people to adapt and change their behavior.

Table 2: Key institutional areas where a more integrated approach is needed (Verzijlbergh et al., 2017)

More price-elasticity of energy demand might be the result of changes on the institutional level described above, meaning that the demand will adapt more heavily on the price. This will have a stabilizing effect on the electricity system. Policies that promote such a shift may need to be considered instead of the current policies, that essentially stimulate energy-intensive industries. New decision-making tools and models are required to capture the complex interdependencies of a renewable energy source based electricity system (Verzijlbergh et al., 2017).

3.6. Conceptual Model

The theories, ideas and concepts from the previous sections result in the conceptual model. The conceptual model is mainly a summary of all used concepts and shows how those concepts are related to each other. Specifically a connection between transition theory and the Dutch electricity grid, electricity storage, smart grids and institutional barriers is made. The conceptual model also serves as a tool for the next steps in this research and will be tested in the next phase of this study. This study aims at providing insights to the institutional design of smart grids in order to contribute to smart grid development. This all happens in the context of the energy transition as the transition towards renewables challenges the current electricity grid and its reliability. Therefore, the current grid needs to undergo changes as well as the institutional conditions that could enable these changes.

This chapter started with the topic of the Dutch electricity grid as it is useful to have an understanding of its history and organization. Secondly the transition theory and the energy transition were discussed because of the context of the energy transition and the transition towards a smart grid. Thirdyly, electrical energy storage was discussed as it is seen as an important contributor to solve the issue of a fluctuating electricity output and an inherent part of smart grids. In 3.5. the definition and relevance of an institutional design has been discussed, including the institutional areas that require change.

This study will also take into account the applicability of blockchain in smart grid development. Blockchain technology could possible contribute to a secure smart grid, but as it is a possible technological innovation that can be used in smart grid, it is not linked to the institutional design directly.

Together, this forms the following conceptual model:

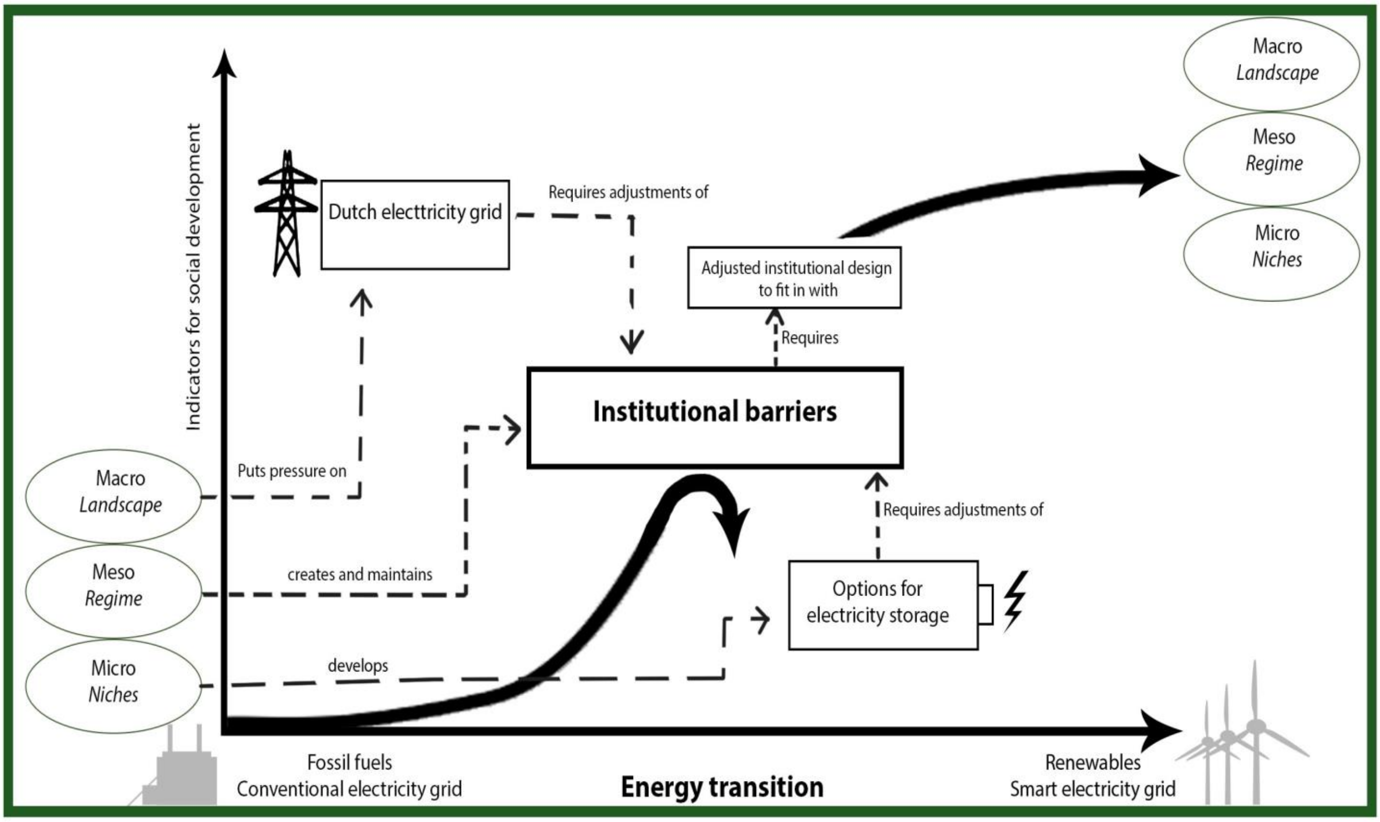

Figure 10: Conceptual model

The conceptual model shows that institutional barriers are hindering the transition toward a smart electricity grid. This is shown by the arrow not continuing towards the acceleration phase because of the institutional barriers created and maintained by regime actors. On the left side of the conceptual model the three layers from the multi-level perspective can be seen. The macro levels puts pressure on the Dutch electricity grid as the grid cannot seem to keep up with the developments on the macro level. Actors from the micro level develop options for electricity storage, such as batteries from electric vehicles. Before those can be implemented on a larger scale, adjustments of the institutional design are required. Eventually an adjusted institutional design should allow the implementation of a smart electricity grid. At the top right of the conceptual model the three layers from the multi-level perspective can be found again, but this time they represent the layers of social organization in a smart grid. It is difficult to predict how the layers will be organized once the transition toward a smart grid reaches the stabilization phase, which is when the top right corner of the conceptual model is reached. But as transition theory has pointed out, stabilization does not necessarily mean the end: when an equilibrium is reached a new transition could rise.

Chapter 4 – Methodology

This section will explain the methodology behind this master thesis. The aim and goals of research will be discussed, as well as the methods to reach those goals and how collected data will be gathered and analysed.

This chapter starts with a short explanation of the research strategy. Then, the aim and goals of this thesis are discussed. Thirdly, the research methods are introduced. Chapter 4 ends with a framework that shows the data collection and research methods.

4.1. Research strategy

So far, this thesis has introduced a problem, positioned the objective and presented a theoretical framework followed by a conceptual model to use as a tool for further research. This section discusses the parts that make up the research strategy.

It is important to make clear that this thesis has used a flexible research design with an iterative, cyclical approach. This means that during the process of this qualitative research the research questions may be, and have been, changed over time based on the collected data. Newly formulated research questions also lead to an adjusted process of data collection and analyzation (Kerssens-Van Drongelen, 2001).

Positioning of the objective

Chapter 2 focussed on the positioning of the objective. The necessity of this is a result of the complexity of the objective. Emphasizing on the positioning of the objective is helpful for formulating research questions and helps in the structuring of the theoretical framework. Positioning the objective is useful before gaining an understanding of a complex objective.

Understanding the objective

After the positioning of the objective the theoretical framework has been presented to gain an understanding of the objective. Gaining understanding of the objective has been done with a literature study. On the topics where academic literature could not provide enough information that was required, a desk research has taken place. The theoretical framework resulted in the conceptual model (section 3.6.) which can be seen as a summary of the understanding of the objective.

Using the theoretical framework as a tool

The conceptual model is a tool for further research. The further research has taken place in the form of semi-structured interviews. At some points academic literature has been used to supplement the results from the semi-structured interviews. The reason for this is that the literature itself did not fit in with the understanding of the objective but did provide useful extra data for the answering of the research questions.

4.2. Research aim and goals

Research usually refers to a search for knowledge and is considered an academic activity. It can also be defined as a systematic and scientific search for pragmatic information on a specific topic. Therefore, research contributes to existing information on a certain topic and aims at its advancement. Research can have different purposes (Kothari, 2004).

This study aims to provide new insights on the institutional conditions that obstruct smart grid projects to be realized, with special attention for the fuzzy character of certain concepts, electrical energy storage and the applicability of blockchain technology. Studies that aim at gaining familiarity with a phenomenon or gaining insight into it are called explorative or formulative studies (Kothari, 2004). This research can also be seen as an explorative research. Its goal is to provide insight on institutional barriers, or the 'outdated the rules of the game'.

The research questions mentioned in 2.4. form the basis of this research and for reaching the goal. By answering the research questions and the main question, conclusions should be drawn that can be useful for stakeholders in the energy sector that are interested in the development of the Dutch electricity grid. Interests in and positions on a smart grid will likely differ. Therefore it would be ideal to take into account different viewpoints. This is the case with any important concept with a character that can be described as 'fuzzy'. To get a good understanding of the blockchain technology, experts from the development side of blockchain also have to be consulted. As this research is concerned with a subjective assessment of opinions and attitudes it can be seen as a research with a qualitative approach. Common techniques used in qualitative research are focus groups and depth interviews (Kothari, 2004). Of those methods, depth interviews have taken place in this research. Those depth interviews will focus on grid operators as they are directly involved with smart grid development.

Several methods have been used to reach the research goals. First, a literature study was conducted to form a theoretical basis and to contribute to formulating and answering several research questions. The theoretical basis did not provide enough information, so a document analysis took place. As the research is explorative and focuses on the electricity grid of the future, a document analysis is not considered a main source of data. Furthermore, interviews were held with grid operators. The interviews should result in insights that are based on experiences from grid operators in practice.

4.3. Literature study and selected theories

This thesis aims at gaining an understanding of what institutional barriers lie ahead for the realization of smart grids. A framework based on findings from literature has been constructed, as there is no empirical data available. These findings have been supplemented with findings from a desk research and will be tested in practice by conducting (semi-structured) interviews. The logic behind this is that there will not be many respondents to derive quantitative data from, and that semi-structured interviews provide the opportunity to gain qualitative data from stakeholders with different interests and backgrounds in a more flexible way.

The literature study is based on a selection of international scientific literature. As smart grids and its institutional conditions form a topic that has emerged quite recently in literature and progress on those topics is made quickly, literature that is several years old can already be seen as outdated. Given this situation, mainly recent literature will be used regarding those topics. The scientific literature and relevant theories used have been found with the use of Google Scholar and the library catalogue of the University of Groningen.

The selection of literature was done on the basis of the problem and objective presented in chapter 1. The complexity of the problem made a positioning of the objective a useful step. For chapter 3 mostly literature from academic journals on the topics of energy and energy policy have been used. These sources contain a wide range of policy implications of energy supply and use. As the outdated rules of the game in society will be identified in this thesis, it is logical to have a deeper look into the policy-making side: policy-making is required for an intentional transformation of institutions. Besides literature on energy and energy policy there has been a focus on transitions. A transition perspective is highly relevant for this thesis: a transition from a conventional electricity grid to a smart electricity grid is desirable in the context of the energy transition. This resulted in the use of transition theory as the backbone of the theoretical framework. The multi-level perspective of transition theory can also be connected to the three levels of institutional design and to a certain degree to the organizational levels of the Dutch electricity grid.

One could argue that it would also make sense to look at the problem and objective from different perspectives. Energy itself is a fundamental term in the world of physics. Looking at the technical side and mechanics of various forms of energy could provide useful insights regarding the transition from conventional grid to smart grid. However, this thesis focuses on non-technical barriers for the implementation of smart grids. A deeper look into the technical design of components of the electricity grid would also make sense, but does not fit in with a focus on institutional design.

A reflection on the used literature takes place in chapter 6. It will be argued if the literature selection and theories have been appropriate for this research. The critical reflection will expose the strengths and weaknesses of the theoretical framework. This is done to contribute to theoretical debates and to propose modifications to theories.

Besides the literature from academic journals a desk research has been conducted. The following documents and articles have been used to supplement the findings from academic literature:

Authority of Consumers and Markets (ACM):
2018a: Ontheffing aanwijzen netbeheerder
2018b: De energiemarkt

Tennet:
2018a: Grid operators
2018b: Our high voltage grid
2017c: Gridmap Netherlands

Rijksoverheid (2019):
Klimaatakkoord

The desk research also includes two journalistic articles, showing the actuality of the research and indirectly adding commentary from actors in the energy sector. These journalistic articles are:

NL Times:
2018: Netherlands electricity grid struggling under explosive growth of solar parks

NOS:
(2018b): Grilligheid zon en wind bedreigt stabiliteit elektriciteitsnet

4.4. Semi-structured interviews

During this research interviews will take place with experts on the topic of smart grid projects. More specifically, semi-structured interviews will take place as they are a key method for gathering information in an explorative study (Kothari, 2004). They also give the researcher more freedom in the asking of questions, as they allow follow-up questions to be asked and possible answers to be linked with each other.

Experts involved with smart grids and familiar with its institutional conditions will be interviewed. A certain flexibility regarding the questions is necessary to take into account different backgrounds and roles. A disadvantage of this method is that results will be less suitable for comparison. A basis of central questions will provide structure to the interviews, whilst some sub questions will be only relevant for a specific expert.

After consulting the supervisor of this research it has been decided that gathering insights from an expert on the technical development side of blockchain technology is a good idea. This is a useful start as someone with a planning background is less familiar with the possibilities and limitations of the technology.

Experts that would be highly relevant are actors who are involved in operating and upgrading the electricity grid, specifically those who are familiar with smart grid development. They are the ones that might have faced institutional barriers and can provide ideas for new rules of the game. In 2.1. the operative side of the Dutch electricity grid has been discussed and the national and regional operators have been mentioned. They form ideal experts to interview as they play an important role in the energy transition and flexibility and storage related issues for renewable energy integration. They are also involved with the development of smart grids and face tough decisions regarding investments in the grid.

Three interviews have taken place during this thesis. The first was with Christos Bampis and Bouke Hosper from International Business Machine Corporation, or IBM for short. At first an interview with Christos Bampis was planned, but Bouke Hosper was also invited to provide extra information. Both work at IBM as blockchain developers and have been involved with a blockchain pilot in collaboration with Tennet and Vandebron. The interview took place on the 24th of July 2018 at the IBM office in Groningen. The goal of the interview was to gain insight in the world of blockchain development and in the applicability of blockchain in the electricity grid.

The second interview was with Anton Tijdink of Tennet. He is a policy employee at Tennet at the Customers and Markets department and is involved with Tennets policymaking. The main goals of

Tennet are the building and controlling of the high voltage network, ensuring the business operations of the high voltage network and market facilitation. The interview took place on the 5th of August 2019 at the Tennet main building in Arnhem. The goal of this interview was to gain insight on Tennets perspective as the transmission system operator regarding the institutional design of smart grids.

The third interview was with Ton van Cuijk of Enexis. He is a distribution system operator architect and works at Enexis' department of asset management. Therefore he is involved with future grid operation and focuses on the topic of flexibility. The interview took place on the 5th of August 2019 at the Enexis main building in 's Hertogenbosch, or Den Bosch. The goal of this interview was to gain insight on Enexis' perspective as the distribution system operator regarding the institutional design of smart grids.

The interviews with Tennet and Enexis were held in Dutch as both the interviewer and interviewees were native speakers of Dutch. The interview with IBM was held in English as not everyone was fluent in Dutch. The audio of the semi-structured interviews has been recorded as there was permission given by the interviewees.

4.5. Analysis and framework of data collection

As this study uses a qualitative approach, no rigorous quantitative analysis will take place. The results therefore will also come in a non-quantitative form.

For the analysis of the collected and used literature that forms the theoretical framework, no specific technique has been used. Insights have been gathered from literature on a range of topics. A critical reflection has taken place on the literature to possibly provide contributions to theoretical debates. Possible connections between scientific theories have also been made.

The recordings of the semi-structured interviews have been fully transcribed. The most relevant parts that contribute to answering the research questions have been selected to be presented in chapter 5. A coding scheme based on the conceptual model is used for the interviews with Tennet and Enexis as an analytical strategy that is in line with the theoretical framework. As the interview with IBM covered a smaller range of topics, no coding scheme was used.

The link between the research sub questions and research methods can be found below in table 3.

Research question	**Data**	**Method**
How can the current electricity grid of the Netherlands be conceptualized and how is it operated?	Theoretical foundation from existing literature (articles from scientific journals and books), information from grid operators	Literature study on Dutch electricity grid development and operation, desk research on grid operation
When can an electricity grid be considered a smart grid?	Theoretical foundation from existing literature (articles from scientific journals and books), information from grid operators	Literature study on smart grids and semi-structured interviews
To what extent can the current electricity grid of the Netherlands be considered smart?	Information from grid operators	Semi-structured interviews
What changes need to be made to facilitate a growing share of renewables in a smart grid and what consequences do these bring?	Theoretical foundation from existing literature (articles from scientific journals and books)	Literature study on smart grids and energy storage
How can the developments of the grid be seen from a transition theory perspective?	Theoretical foundation from existing literature (articles from scientific journals and books), information from grid operators	Literature study on transition theory, semi-structured interviews
What is the state of the institutional design for energy storage?	Information from grid operators	Semi-structured interviews
How can the fuzzy character of blockchain be unraveled and how could the technology contribute to the smart grid?	Theoretical foundation from existing literature (articles from scientific journals and books), information from blockchain developers	Literature study on blockchain and blockchain-based smart grids, semi-structured interview

Table 3: Framework of data collection and research methods.

Chapter 5 – Results

In this chapter the gathered data from both literature and semi-structured interviews will be presented and analyzed. The results from this chapter should lead to conclusions that will provide answers to the research questions that were introduced in 2.4..

The structure of the chapter is in accordance with the theoretical framework. Section 5.1. covers the Dutch electricity grid, 5.2. covers transition theory, 5.3. covers energy storage, 5.4. covers smart grids and 5.5. covers institutional design. Therefore this chapter has a similar structure to chapter 3. It should be noted that the section about smart grids will also focus explicitly on the role of users, their data and blockchain technology. The reason for this is that section 3.4. has pointed out that more emphasis will be put on user privacy and cybersecurity when the electricity grid starts to facilitate both flows of energy and information.

This chapter uses the conceptual model of section 3.6. as an analytical tool. The concepts of the conceptual framework and their relationships are tested to gain insights, most importantly on the institutional barriers for smart grid implementation.

5.1. Analysis of the Dutch grid operation

The Dutch electricity grid has been introduced in 3.1.. One of the most important statements was that the operation of the grid is strictly separated. According to the respondent of national grid operator Tennet (2019), this is indeed the case. However, the layers of the grid appear to becoming more and more intertwined. Tennet (2019) states that *"now that power can flow in the other direction, you can notice that you're more entangled with each other than you originally determined on paper".* At the moment, Tennet is responsible for all the networks above 110 kilovolt, and everything underneath is in the hands of the regional grid operators. The respondent of regional grid operator Enexis (2019) agrees that the grid layers are physically separated and hierarchically organized, but that the flows on the grids are becoming more dynamic because of the rapid advancement of the energy transition. *"It means that you get production of electricity in the capillaries of the grid, and that is not what is was established for"* (Enexis 2019). The respondent of Enexis also thinks that the role of operators could change because of this situation.

According to Tennets interviewee, the entanglement of the grid layers is one of the results of the energy transition, bringing a new dynamic. An important reason for the increased entanglement is decentralized production. *"At first, production was mostly connected to our grid. When you talk about decentralized production without wind, it's more and more in the lower grids"* (Tennet, 2019). This leads to congestion forming in the lower grids. The problem of such congestion is not limited to the lower grids, but also has an effect on the grid Tennet operates as the scale of the problem rises. The congestion has influence on both the operation of the grid and the electricity market. A large producer of solar energy could be in trouble because of congestion, which primarily forms a problem for regional grid operators as the producer is connected to their grid. Tennets interviewee (2019) adds that *"when it is a lot, we will see it in our flows too".* Centralized producers offer possibilities for arrangements to switch off production, but the more decentralized production becomes the more difficult it is to limit production.

Decentralized production appears to be difficult to influence for grid operators. Tennets interviewee (2019) sees a rapid development of decentralized production, and states *that "grid operators are being confronted by a quickly advancing energy transition".* Part of the advancing transition is expressed in increasing investments in sustainable energy: *"the grid investments are lagging behind the investments in sustainable energy"* (Tennet 2019). The interviewee of Tennet sees the current system as a robust one but states that there is little information available on what is happening in the lower grids in real-time.

Decentralized producers can currently not always be connected to the grid. These producers would of course like to see regional grid operators to find a solution quickly. *"The money we spend is all societal costs, eventually they will return to civilians. So we want to handle it as a good pater familias"* (Enexis, 2019*).* Therefore buying flexibility by spending money to not connect solar energy to the grid is a waste of public money. *"There need to be made responsible choices, and those aren't easy*" (Enexis, 2019). The role of grid operators, according to the interviewee of Enexis, is especially facilitating.

5.2. Analysis of the energy transition and transition theory

In section 3.2. energy transition and transition theory have been described and it became clear that regime actors can be considered as dominant in the energy sector. Policymaking is mostly done by actors that fit into the existing regime, who are in turn influenced by pressures from the landscape level.

The national and regional grid operators notice an acceleration in the energy transition. The interviewee of Tennet even goes as far as stating that *"grid operators are being confronted by a quickly advancing energy transition".* Looking at the S-curve that includes the phases of a transition, it seems that the energy transition has neared or arrived at the acceleration phase.

The take-off phase includes a starting shift of the complete system with a merging of different ideas into once, more or less consistent pattern. In the acceleration phase visible structural changes take place and react to each other. During this phase the actors from the regime level have an enabling role and dominant practices change.

It is of course difficult to determine at which exact moment a new phase has arrived. It is clear that the take-off phase has been reached, as distributed production on lower levels of the electricity grid imply a shifting system. The acceleration phase is reached when dominant practices change and visible structural changes take place and react to each other. In some areas in the Netherlands the grid infrastructure can not facilitate any more production from renewables, leading to a situation where investments in the grid infrastructure are lagging behind the investments in production. Especially regional grid operators face increased distributed production and lead to changes in their grid operation.

Regarding the situation of dominant regime actors, the interviewee of Tennet (2019) stresses that the unit size of power is a crucial factor. He sees the electricity market as a market that is based on a centralized model, and that *"you can think that you are a big player with a residential consumption of 3500 kilowatt hours, but we are talking about terawatts. It is a completely different order of magnitude".* This situation means that it appears indeed difficult for micro level actors to have influence on policymaking. *"When an aggregator has ten thousands of batteries, he could maybe offer one or several megawatts on the electricity market. Will we stop that? I don't think so. I think there are a lot of possibilities for aggregators to do that."* But before this can be put into practice, economic barriers need to be overcome.

The question, according to the interviewee of Tennet, is: *"is the consumer obstructed, or is it economically not viable?"* He adds that this can be sometimes underestimated by parties that promote consumer interests. Micro level actors could be empowered by changing level playing field market rules, but they will likely have a too little role to make the efforts worth it.

5.3. Analysis of energy storage

In 4.1. it has become clear that grid operators are being faced by a rapidly increasing energy transition, resulting in increased centralized production. This lead to congestion and calls for solutions. Looking at the solutions, the interviewee of Tennet (2019) states that *"they have to be of a certain scale. When we have problems in the grids we're talking about tens or hundreds of megawatts".*

Many options exist to store energy or to increase the flexibility of the grid. *"When supply and demand can meet, you are flexible enough"* Tennet (2019) metions. An important factor in finding solutions is the role of grid operators. They should not participate in commercial activities, according to Tennet. When a battery could be placed in an area such as the Northeast of the Netherlands, market parties have to execute the placement. *"We'd have to put out a tender for a market party to do that"*. The interviewee of Enexis (2019) shares this view, and thinks that market parties can find the best solutions. If a market party does not come up with an economically attractive solution, *"a different market party will come to meet my demand for a better price".* Looking for a solution in a technically neutral way to allow the market to find solutions is something both the operators have a high trust in. "*We will ask for flexibility in a functional way, and it is up to the market to choose which technology fits in the best"* (Enexis, 2019).

Market parties that invest in solutions such as batteries already exist and try make it commercially marketable. So far, it appears to be economically viable for batteries on the market for the so-called frequency containment reserve (FCR). *"In Europe we permanently contract capacity to support the frequency"*, the interviewee of Tennet (2019) states regarding this matter. The investments made in batteries can be earned back as batteries can be placed for relatively cheap and the prices paid for FCR are on a high enough level. More and more batteries enter the FCR market, but the FCR market is limited to 3000 megawatt in Europe. The Netherlands is contracted to facilitate 107 megawatt and currently has around 30 megawatt supplied by parties with a battery.

Regarding the different forms of energy storage, the interviewee of Tennet (2019) stresses that *"everything you can do electrically you should do electrically"*, as efficiency losses appear when using for example hydrogen-based solutions. Overproduction of wind and solar power can be made into hydrogen, but other forms might be economically more viable. Transforming electrical energy into heat could be a good option, but *"when you have stored it in heat you cannot transform it back into electricity"* (Tennet, 2019). A combination of storage forms will likely have to contribute to solving the problem of a fluctuating electricity supply.

International connections could also greatly contribute. The interviewee of Tennet (2019) states that these contributions are also limited. "*When there is no wind blowing and no sun shining here, it will also not be the case in England and likely for a large part of Germany, and definitely not at a level that gives them overcapacity to give to us.*" At the same time, according to the interviewee of Enexis (2019), the international connections are becoming more important when the share of renewables rises.

An area that shows great promise is the area of electric vehicles. *"I firmly believe in the good prognosis of electric vehicles, which could be 3 million by 2030. There are many market possibilities for electric vehicles and you'll use it for transportation, possibly primarily. But you have a large battery to marketize, and I think people will do that more or less"* the interviewee of Tennet (2019) says. Besides the market possibilities of the battery, propositions could be made to lower the peak of electricity consumption in the evening. Cars could be charged during the day, perhaps leading to a type of reward by an energy supplier. When the batteries of the electric vehicles are pooled they could especially compete with other forms of storage. *"I think it is going to be an important player that will be a buffer in the electricity market"* Tennets interviewee (2019) states, but adds that *"you shouldn't think it is going to solve everything. Far from it".*

The interviewee of Enexis (2019) also thinks that electric vehicles show great promise, coming from the fact that mobility is a need for which people want to invest and that the batteries of electric vehicles aren't being used 90% of the time. He adds that freedom will remain for users, as not everyone will want to charge their vehicle at a different time. This will however lead to costs that need to be paid by the user.

Finally, it should be noted that influencing demand response might be better than storing energy. The interviewee of Enexis (2019) states that influencing the usage will always be cheaper than storage.

5.4. Analysis of the smart grid

This section presents the findings regarding smart grids. Smart grid definitions, the changing role of users, grid security and blockchain technology are highlighted. The current smartness of the electricity grid is also discussed.

5.4.1. Defining smart grids

The definition of a smart grid has been discussed in 3.4.., but still the term can be seen as fuzzy. Therefore it is useful to discuss the definition of a smart grid with the grid operators and to ask when an electricity grid can be considered 'smart'.

"It is a wide term for a lot of cleverness in your grid. To me it still feels a little bit like a container concept" the interviewee of Tennet (2019) states. The interviewee of Enexis (2019) also uses the term container concept when the definition of a smart grid is mentioned. The essence of the transition to smart grid, according to Tennets interviewee, is the fact that there is more information available from devices in the grid and that they are made steerable. This transition

bring quite some IT-investments. Enexis also sees the availability of information as crucial when it comes to smart grids, but that the information is useless when you cannot act on it.

The current grid is a *“very conventional and large grid that works quite analogue, is quite robust and has a lot of buffers”* (Tennet, 2019). The grid is constructed that way to operate it safely because it is unclear what everyone is doing individually. Tennets interviewee thinks that smart grids bring a new range of possibilities to bring supply and demand together and that they formulate problems in the grid in the market demand, so that devices can react to it. The scale at which these possibilities can be implemented remains unclear. *“If millions of households make their devices accessible for an aggregator that can actually turn the devices on and off, then you can make actual propositions. But the question is if people really want that. Perhaps with a million electric vehicles, you can possibly intervene there”* (Tennet, 2019).

It a appears that a controlling and steering devices is an important factor when it comes to the concept of a smart grid. But smart grids are not limited to measuring and steering. *“There are people who think a lot further, about artificial intelligence, self-steering, blockchain…”.* Tennets interviewee (2019) thinks the basis of the grid is not yet smart enough to facilitate such things, but mentions that Tennet is thinking along with diverse parties involved in smart grid pilots and has interest in such developments. *“At the moment where you don’t need any human interactions your are finished. But I think that’s a pretty futuristic image”* (Tennet, 2019).

So far, the term smart grid has been used in both singular and plural form. According to Tennets interviewee (2019), it is common that local or small smart grids are being mentioned, but that *“We have one large European grid. It is all connected to each other”.* Certain elements of the current electricity grid can already be seen as smart, according to Tennets interviewee. Large installations on the grid can already be steered, sometimes quite directly. The interviewee of Tennet also sees an increase in possibilities to steer and adjustments being made to regulations to enable these possibilities.

However, when discussing smart grids it should be noted that there still is quite a way to go. *“You are often talking about an electricity system that isn’t there yet. We do not yet have a 70% infeed of renewables”* (Tennet, 2019). As the real problems and challenges of large-scale renewable energy production have not yet appeared, there is not a lot of variability yet that needs to be covered. This means that the need for facilitating flexibility with large-scale smart grid enrollment is currently not that big. This situation could change quickly however, as the grid operators see a quickly advancing energy transition.

5.4.2. The changing role of users

With the introduction of smart grids, the role of the user can also be expected to change, depending on the smart grid vision. Obinna et al. (2017) expect that the role of users is to become more active. Through for example advanced sensing, communication and control technologies consumers could receive greater information and choice. Their role would change based on exporting power to the network, demand participation and energy efficiency (Chandler, 2008, cited by Verbong et al., 2013). Therefore, the social dimension of smart grids is not to be ignored.

According to Aitzhan & Svetinovic (2018), a centralized energy trading infrastructure raises two concerns:

- A single point of failure: failure of a centralized third party in a network can obstruct availability and the reliability of security
- Lack of privacy and security: a centralized middleman can reveal patterns of energy generation and predict an agent's activities

The importance of preserving identity privacy is shared by Naus et al. (2014). They state that privacy concerns have slowed down the development of smart energy technologies in the Netherlands. A transition to a smart grid would bring challenges for many involved parties, as the energy system itself can be seen as a complex web of interrelated networks in a physical, economic, social and institutional way. Therefore, renewable energy projects are not possible on all locations. (De Boer & Zuidema, 2015). De Beaufort et al. (2017) claim that energy systems are already evolving towards more decentralized systems that are more suitable for peer to peer energy transactions through a microgrid infrastructure. A reason for this is the rapid growth in the deployment of distributed energy prosumers (Pop et al., 2018).

Smart grid pilot projects in Groningen, the Netherlands, and Texas, United States, have revealed that electricity usage was lowered after implementation. Both consumption and increased self-generation of electricity showed great potential for contributing to balance electricity demand and supply. A remarkable conclusion from both projects was that residential users preferred technologies that automatically arranged their energy usage, as this resulted in minimal effort for the users. User experiences also revealed that not all participants were capable of using the pilot technologies (Obinna et al., 2017).

The interviewee of Enexis (2019) states that it crucial for the development of smart grids to bring incentives to end users. After bringing the incentive to users, the rest of the development should follow quickly. *"The grid operator is responsible for an efficient usage of the grid, so you have to make sure there is an incentive for the costumer, the end user, to use the grid efficiently"* (Enexis, 2019). Aggregators could play a role in this, but they form an extra layer between users and grid operators.

5.4.3. Privacy and security in the smart grid

According to Chan and Zhou (2013), the area of cybersecurity regarding smart grids is one with many doubts. They claim it is widely agreed that smart grid designs, smart meters in particular, are vulnerable to various attacks. Verbong et al. (2013) go as far as stating that privacy concerns can block a successful introduction of smart grids and demand side management. They state that involved actors get a lot of information on user behavior and regard the privacy issue as important. There also seem to be no security requirements for smart grid applications. Smart grid designers face a lack of standards on the topic of cybersecurity (Chan and Zhou, 2013). As the government of the Netherlands wants to have smart meters in every household by 2020, this can be considered a topic worth investigating. The current advanced metering devices are, according to Wolsink (2012), essentially tools that are operated by energy suppliers or grid managers. They offer information regarding energy demand and supply to centralized actors, fitting in with the institutional frame.

The interviewee of Tennet (2019) states that there is a discussion regarding privacy, and that smart meters can possibly reveal a lot of someone's life pattern: *"You can probably see in households if you are dealing with a dual income household or if the owners are at home all day".* Enexis' interviewee (2019) states that operators do not have access to detailed data because of privacy issues: *"I think it's worrying that there is so little confidence in companies like Enexis".* Because of this, grid operators are limited to their own measurements and potential efficiency benefits cannot be accomplished. The Enexis interviewee however does understand that companies such as Facebook and Google have changed the way users think about data usage.

Smart meter implementation in the Netherlands has encountered problems on the subjects of privacy and autonomy, as there has been resistance by residents against what they perceived as commercial strategies of energy companies and new surveillance methods (Naus et al., 2014). Naus et al. (2015) add that privacy and autonomy concerns impede the participation of households, who are increasingly seen as participative actors with the responsibility to act as change agents. The Dutch government started planning the implementation of smart meters at an early stage. The government encountered several setbacks, as issues regarding privacy and security emerged. Civil society organizations and parliament members voiced their concerns and questioned the mandatory installation of smart meters, as well as smart meter vulnerability and data usage. This lead to a revisioning of the smart meter bill in 2009 and the delay of small and large scale smart meter rollout. The new bill included a bi-monthly transfer of energy data and overviews of energy usage, as well as making smart meter installation no longer mandatory (Naus et al., 2015). According to Naus et al. (2015), the political support of the development of smart grid technologies has been slowed down since the privacy and security concerns emerged from civil society organizations and parliament members.

Rolling out a smart meter infrastructure can be considered the first step in the vision of a smart grid application for the distribution grid operator (Engerati, 2017). As of 2016, there already were 700 million smart meters installed worldwide, with a total amount of $14,3 billion USD invested. In May 2018, there were 900.000 smart meters installed by regional operator Enexis alone. The Intelligent Grids Innovation Programme of the Dutch government has ensured that 94 smart meter pilot projects have started with government funding. It is clear that the Dutch government is enthusiastic about smart meters (Power Technology, 2018). Smart meters increase the awareness for end users on their usage and savings. The users can immediately see the effect of their daily activities on the household energy usage or savings, expressed in monetary terms. Smart meters also make a quick respond from the relevant operator possible whenever there is a problem (Power Technology, 2018). Chan and Zhou (2013) state a possible reason for the high trust in the potential of smart meters: there is a common presumption that utility operators can always be trusted and therefore require no guarding. Chan and Zhou (2013, p. 65) state this is "too strong an assumption for consumer privacy in smart grid applications". They put emphasis on vulnerable areas within the EV facilitating infrastructure, with device authentication and EV user location privacy mentioned as two areas where breaches could possibly occur. Cavoukian et al. (2010) share the view that cybersecurity should be a crucial element of smart grid design, and state that these consumer-focused elements of control and transparency are crucial for the design as a lack of such elements will lead to major concerns. The importance of adding cybersecurity to smart grid design is also stressed by Fang et al. (2012). They claim that possible risks should be assessed when adding new technologies to the grid: those technologies have both the potential to empower the defence against attacks and failures, but also bring vulnerabilities.

At the moment, it seems unclear who will eventually have access to what electricity usage data, for what purpose and how data privacy will be guaranteed. In the meantime smart meters are installed in households worldwide. In the Netherlands, these meters contain simcards that are connected to the 2G network. The 2G network itself is currently being phased out, forming a problem for grid operators. New simcards are being created to both counter this problem and to avoid a mobile operator lock-in situation. The fact that IT equipment has a lifespan of about 10 years adds vulnerability as well (Power Technology, 2018).

The interviewee of Enexis (2019) states that the dependency on energy in the world increases the risk of something going wrong with a more digitalized energy system. According to the Enexis interviewee (2019) the operators are aware of this situation and states regarding attacks on the system that "*when we automatize and digitalize, we make sure that especially for our vital stations it is not possible".*

5.4.4. The applicability of blockchain in smart grids

This section will focus on blockchain technology. The origins and definitions of blockchain are introduced to gain a basic understanding. Its potential for the energy sector, specifically the electricity grid, will also be discussed. A link with theory is made to put emphasis on how a technical innovation can spread throughout society.

The word blockchain surfaced first in a 2008 paper by Satoshi Nakamoto, where he described the technology underlying the cryptocurrency Bitcoin: a series of data blocks that are chained together in a cryptographically way. The Bitcoin cryptocurrency was the first practical application of the technology, and since then has quickly gained popularity which resulted in terms such as *the blockchain economy* and *blockchain revolution* (Mattila, 2016). Berg et al. (2017) call blockchain one of the most significant inventions of the 21st century.

A blockchain can be seen as a digital, distributed ledger. One could wonder why a type of ledger could be called a revolutionary technology, as it is usually regarded a document associated with accounting. Berg et al. (2017) state that ledgers are essential for making markets more efficient. They also confirm identity, ownership, authority and status. Nowadays, digital ledgers are everywhere, but are *"as reliable as the organization that maintains it"* (Berg et al., 2017, p. 36). This is also explained by blockchain developer Christos Bampis of IBM:

"It's a distributed system, but all the participants have the same ledger so they cannot change the data. As you can have, for example, a centralized application that has only one participant who can give all the information and they can change the data accordingly" (Bampis, 2018).

This is where blockchain can play a role: the ledger becomes distributed and is no longer controlled and validated by one central authority. Seeing a blockchain as a ledger, rather than the technology behind Bitcoin and other cryptocurrencies, also illustrates its potential uses. Käll (2018) describes blockchain as a means that can be used for improving decentralized connectivity between objects De Beaufort et al. (2017) state that blockchains are not only restricted to financial transaction, but can also be used for any kind of digital asset. Furthermore, as a decentralized, distributed ledger diminishes the need of a maintaining authority, third party or government backing, blockchains can not only be used by firms but also replace firms (Berg et al., 2017).

Berg et al. (2017) state that in general a centralized authority has to verify that new information that is added to the database is valid. The authority has to prevent users from making illegitimate transactions. Blockchains rely on peer-to-peer networks and enable databases to be updated, but not modified. Users receive a cryptographic address, to which funds can be sent, and a matching key which is used to withdraw those funds. Käll (2018) sees this as coding property control into property objects themselves, removing the need of monitoring property rights.

On establishing a blockchain, De Beaufort et al. (2017) state that the blockchain is constructed by adding blocks to a chain of data. By doing this, continuous and unalterable records are formed. The blocks are connected to the previous block and consist of useful information, such as a signature, a timestamp or transaction data. The process is based on a peer to peer network protocol. Every node verifies the block with a cryptographic calculation, and will notify other nodes whenever a block is verified as legitimate. Furthermore, as a decentralized, distributed ledger diminishes the need of a maintaining authority, third party or government backing, blockchains can not only be used by firms but also replace firms (Berg et al., 2017). Currently, blockchain is still in an early phase. Blockchain developer Bouke Hosper states that there is a strong interest for using the technology. *"A lot of people with a business want to put everything on the blockchain, all their data. And that's not really what it's made for, to put everything on the blockchain. We're still working on scalability, on improving transactions per second, on the amount of data you can put in"* (Hosper, 2018). Christos Bampis shares this view, and claims that blockchain is not always the best option or even applicable. "*If you're the only participant involved and you don't have trust issues with other participants, maybe just having a single database and not having a blockchain technology is better than investing in servers and applications. And this is, sometimes people are trying to fit blockchain everywhere, but it's not applicable all the time (Bampis, 2018)."* He adds that at this moment the fields with the highest applicability are those regarding supply chains, certificates and verification claims.

Most literature focuses on the potential benefits of blockchain technology. Regarding drawbacks of the technology, Aitzhan & Svetinovic (2018) state that the number of transactions a blockchain can process per second has to be able to endure the number of transactions in the real world. They also mention that the technology does not allow participants to perform transactions with assets they do not own. These are issues that limit blockchain implementation in the energy sector and challenges for businesses. Another issue mentioned by Basden and Cotrell (2017) is that a blockchain-based database requires quite some computing power and thus investment costs for participants. The view that blockchain may replace or partially replace utilities is called simplistic and extreme by Basden and Cotrell (2017). Nonetheless, pilot projects with the technology in the energy sector symbolize the potential several energy sector actors see in blockchain.

An unalterable database

Electricity trading and storage in a decentralized approach with both transaction security and identity privacy could benefit from a blockchain based infrastructure as it is praised as a foundation for an unalterable database. A reliance on a trusted third party would, according to literature, be replaced or partially be replaced with a cryptographically constructed chain of data. All nodes would together replace the trusted third party. However, a transformation towards a peer-to-peer system based on blockchain does not exactly fit in with the 'rules of the game' hierarchal grid system as incumbent actors on the regime level seem to have a large influence on policymaking. Basden and Cottrell (2017) think that it is more likely to happen that blockchain will be a part of distributed hybrid system of both large, centralized power plants and distributed energy sources.

The importance of safety and reliability has also been encountered in the blockchain pilot of Tennet, Vandebron and IBM. ”*Because it's the energy sector, it's quite important that everything happens in a safe way. So we have to set up the network over VPN's and all that kind of stuff, because safety is a high priority. And security audits have been done, so security is really important. (…) …it made it less easy than for example some other pilots we did for other clients”* (Hosper, 2018). Regarding the data accessibility of the involved parties in the project, Bampis (2018) states that *“you have access to what you agreed to share”.* Permissions can be set for different users, which results in differences in data accessibility and data alteration possibilities.

In search of a reliable balance of renewable energy generation and consumption, Mengelkamp et al. (2018b) researched possibilities for a microgrid energy market based on blockchain technology, as microgrid energy markets could increase supply reliability by providing energy in cases of power outages of the superordinate grid. Their case study of Brooklyn, New York, showed that blockchains are suitable information systems for facilitating localized energy markets, although connections between microgrid markets themselves and economic and socio-economic consequences for the entire energy supply system and participants should be further investigated. This does not necessarily mean that a blockchain (micro)grid will result in a difference for end users. “*It's like a backbone, so for most blockchain implementations actually the consumer should not really notice that it's using blockchain, right?”* (Hosper, 2018).

Basden and Cottrell (2017) mention that there are several specific areas in the energy sector that blockchain could play a role in. A trading system in which businesses and other actors can trade timeslots during which they can use electricity is mentioned as way to improve flexibility and efficiency for grid operators. Basden and Cottrell (2017) also state that blockchain can enable users to switch between power suppliers more quickly. British startup Electron has worked on a platform that enabled users to switch between supplier within a day. A blockchain-based smart grid simulation of Aitzhan & Svetinovic (2018) led to the conclusion that a blockchain-based energy system can also resist significant attacks and protect user and financial profile privacy and security. Basden and Cottrell (2017) add to this benefit that, when blockchain would be involved in smart grid management systems, problems and emergencies within the network could be quickly identified and reacted to.

Aitzhan & Svetinovic (2018) argue that a decentralized energy trading system without the presence of a trusted third party could provide transaction security and identity privacy. A possible form in which this could be implemented is a system where all nodes collectively replace the third party.

According to De Beaufort et al. (2017), blockchain is a promising technology that could play a role in the energy sector. Matilla (2016, p. 3) describes blockchain technology as the next paradigm shift in digital networks, and claims *“it is providing disintermediated, censorship-resistant and tamper-proof digital platforms of distributed trust, open for all to freely innovate and to transact on.”* Theoretically it also can provide efficiency gains on top of existing structures of enterprise- and industry-level systems, as it would remove the need for constant and active intermediated data synchronization and concurrency control. This way, blockchain technology has the potential to influence all layers of society (Mattila, 2016). The quick adaptation of the technology on the technology radars of major industrial companies illustrates the interesting possibilities it promises for autonomous marketplaces (Mattila et al., 2016).

De Beaufort et al. (2017) see it as a technology for trusted monitoring and measurement of energy related assets, which are expected to become more decentralized. They also state that there is much research to be done on both the theoretical foundations and on the relevant business applications for energy management. To fully envision how the direct use of measurement data from embedded instrumentation can be achieved, more experimental settings are required.

A blockchain-based electricity grid, without the need of a central intermediary, could bring small-scale energy initiatives together and contribute to energy grid stability (Mengelkamp et al., 2018a). Recently, pilot projects in Europe have kicked off as well to test this potential. Dutch energy network operator Tennet has worked together with renewable energy provider Vandebron from the Netherlands and German home energy storage producer Sonnen to connect home energy storage systems to the energy gird. This was facilitated by blockchain technology developed by IBM (Tennet, 2017a; 2017b). Sonnen is also involved with NEMoGrid for testing new energy business models, including an investigation on blockchain-based peer to peer energy transactions with pilot projects in Germany, Switzerland and Sweden (Green Tech Media, 2018). In July 2017, the Tokyo Electric Power Company has invested €3 million in Conjoule, a German peer to peer energy trading platform developer (Green Tech Media, 2017). It appears that there is a widespread recognition that blockchain technology is quite promising for the energy market.

5.5. Analysis of the institutional design of the Dutch electricity grid

In 5.2. the findings on energy storage have been discussed and it was mentioned that grid operators themselves are not implementing solutions regarding energy storage. Instead, market parties have to come up with solutions. This means that when congestion appears, a market-neutral tender or similar activity has to be put into practice. *"We have European market regulation and we have the Dutch Electricity Law. You could say: this might be technically the best solution, but we are not allowed to direct towards a technical solution. We have to steer in a technology-neutral way"* the interviewee of Tennet (2019) says regarding this situation. This leads to friction, which is increased by the speed of the installment of solar park as it leads to an increased urge to find solutions.

The process of finding solutions is heavily influenced by the process of permits. *"We have a democratic constitutional state in the Netherlands, and I think we should all be very proud of that, the fact that you can't just shove people aside"* (Tennet, 2019). There are many procedures that give civilians influence, but those procedures might frustrate those who want to advance quickly in the energy transition. Gaining support from the public is therefore important in the energy sector. In practice this leads to solar parks that can be constructed more quickly than the improvements needed for the electricity grid. The interviewee of Enexis (2019) also thinks that there are many procedures based on laws and regulations that result in a slow process. The process is therefore "*often lagging behind reality*" (Enexis, 2019).

The Dutch government has, according to the Enexis interviewee (2019), assigned lower governments such as municipalities to find local solutions regarding energy transition-related problems. They are also expected to work on the topics of heat and mobility. Regional governments in turn need grid operators to assist them: *“the regional government are sometimes, but not always equipped enough to go through the transition. Small municipalities where they don’t have an expert on hydrogen, that makes perfect sense”* (Enexis, 2019).

Looking at the institutional side on a European level, more and more European market integration and regulation can be noticed. *“We are going to implement the Clean Energy Package, so there is a lot more harmonized European regulation. That is the case for more or less all European countries”* (Tennet, 2019). The interviewee of Tennet continues by saying a lot is currently based on the traditional network, but that improvements in the institutional design are being made to allow new players to enter the market, such as battery aggregators. One principle that Tennet is holding on to is the possibility to earn back an investment on the electricity market. This allows market parties to come op with propositions to form solutions.

A lot of the current regulation is established due to the fact that there is limited information available. An increased amount of information, possibly real-time, on the electricity grid lead to adjustments of regulations. The Tennet interviewee (2019) states that *“it is at least moving in the right direction. There are people who think it is going too slow, and that might be right, but a step in the right direction is definitely being made”.*

Another thing that will likely change are the prices for electricity, leading to a change in behavior on the demand side. *“I think that that’s a very important one, more flex coming from the demand side”,* the Tennet interviewee (2019) says. On the other hand, weeks of low production by little wind and sun could lead to high prices. That could lead to, for example, lower consumption by factories and other users which in turn mean that there is a smaller demand to meet.

An area within the institutional design that the Enexis interviewee (2019) highlights is curtailment. Curtailment is an interesting instrument, but grid operators are not allowed to use it. *“When you are allowed and able to apply curtailment, you will automatically accelerate smart grids”.* Curtailment, according to the Enexis interviewee, is an important solution for allowing renewables in areas in the Netherlands that currently face congestion.

It appears that, when looking at the conceptual model from section 3.6., the institutional design is already being adjusted, allowing new players to enter the electricity market. Slow processes are the result of many procedures that have been created to protect rights and can be seen as an institutional barriers. The protection of rights also results in methods like curtailment being unable to use as an instrument.

Institutional areas requiring a more integrated approach

Verzijlbergh et al. (2017) identified six institutional areas that require a more integrated approach, which were presented in table 2 in section 3.5.. Three of those were mentioned by the interviewees from grid operators Tennet and Enexis.

- Short term market design – make the value of resource flexibility visible in market prices. Fluctuating prices can form incentives for end users to use the grid more efficiently. According to the interviewee of Enexis, this will accelerate the development and implementation of smart grids.

- International harmonization of energy policies – an international difference in availability of electricity from renewables should not lead to lowered revenues for producers. It is, according to the interviewee of Tennet, unlikely that this will be a big issue as no wind and sun in the Netherlands probably means no wind and sun in (for example) Germany and England. A situation where neighboring countries have an overproduction and the Netherlands faces a shortage is unlikely to happen. Harmonization of policies in Europe seems to be a noticeable trend though. The interviewee of Tennet stated that all grids in Europe are connected to each other and that acts such as the Clean Energy Package lead to an increasingly harmonized European regulation.

- Social acceptance and a renewed perception of the energy system – continuous cheap electricity might not be available in the future, requiring people to adapt and change their behavior. This is related to the area of the short term market design where fluctuating prices form an incentive for users to use the grid more efficiently: electricity no longer has a fixed price, leading to a renewed perception and adaptation to the situation. This will not apply to every user, as a fair share of users will probably want to keep using electricity the way they are used to, even if it results in a higher electricity bill.

Chapter 6 - Conclusion

This chapter will start with the answering of the research questions and a reflection on the theories used. This is followed by a generalization of the outcomes of this thesis to put everything in a wider perspective and recommendations for future research. The final section of this chapter is a reflection on the research process.

6.1. Answering of the research questions

This section will answer the research questions that have been formulated in section 2.4.. First all the sub questions will be answered, followed by the answering of the main research question of this thesis.

Sub questions:

- *How can the current electricity grid of the Netherlands be conceptualized and how is it operated?*

  The electricity grid of the Netherlands is established in physically hierarchical way, with a high voltage grid operated by Tennet and lower grids operated by regional operators, most importantly Enexis, Liander and Stedin. The operators are all facing a rapidly advancing energy transition, resulting in problems that have to be faced together and a grid layers that are becoming more and more intertwined with each other.

- *When can an electricity grid be considered a smart grid?*

  The two most important elements of a smart grid are an increased availability of detailed, possibly real-time data and increased possibilities to act on the data. Acting on the data is done by steering devices and production. Both data availability and steering possibilities are ensured by IT investments. It appears to be a matter of perception when an electricity grid is considered smart.

- *What changes need to be made to facilitate a growing share of renewables in a smart grid and what consequences do these bring?*

  A greater share of renewables require solutions for a fluctuating energy production. It is important that demand and supply can meet and that a variety of energy storage options become available. Market parties and aggregators will have to come up with solutions for grid operators that contain the best and economically most viable way to store energy. The greater share of renewables also means that electricity prices will likely fluctuate more in the future, leading to incentives for users.

- *To what extent can the current electricity grid of the Netherlands be considered smart?*

  Small parts of the Dutch electricity grid can be considered smart. Privacy issues stand in the way of data availability, meaning that operators are limited to their own data. Operator data is becoming more and more detailed. Little options for steering devices and decentralized production exist, but centralized production can sometimes be steered quite directly. The current grid is therefore not exactly *dumb*, but does not fit into the typical characteristics of smart grid.

- *How can the developments of the grid be seen from a transition theory perspective?*

  Transition theory has pointed out that regime actors are dominant when it comes to smart grid policymaking and being influential in the electricity market. In practice it seemed that lower level actors cannot gain influence because it requires a lot of effort to form a economically viable party that handles large enough quantities to actually pay a role.

- *What is the state of the institutional design for energy storage?*

  Grid operators have to make tough decisions with public money and are looking for market parties to find the best way to store energy. Grid operators have a technology-neutral point of view in this matter. Slow processes exist because of the many civil rights, which an important reason why the institutional design results in slower smart grid implementation than the implantation of decentralized energy production, such as solar parks.

- *How can the fuzzy character of blockchain be unraveled and how could the technology contribute to the smart grid?*

  Blockchain can be seen as a distributed digital ledger that theoretically makes the contained data inalterable. Considering the digitalization of the electricity grid this has potential, although the question remains to what extent this will be noticeable for end users and at what scale it can be implemented. Blockchain has a fuzzy character and is sometimes used as a buzzword that can solve many problems. It could contribute to the smart grid by ensuring the protection of user data, which is important because of existing privacy issues. As grid operators can profit by a greater availability of data, applying blockchain is an interesting option.

Main question:

- *Which institutional conditions form a barrier for implementing smart grids?*

  A slow grid improvement process because of civil rights and privacy issues forms an important barrier when it comes to implementing smart grids. Grid operators cannot use curtailment as a solution and at the moment there is no incentive for end users of the grid to change the demand side. However, grid operators state that the institutional design is definitely moving in the right direction, although some might see this movement as too slow.

A reflection on theory

Transition theory has formed the basis of the theoretical framework of this thesis and played an important role in the conceptual model. The results of chapter 5 made several things clear regarding transition theory.

In 3.2.1. the phases of a transition have been introduced, being a pre-development phase, a take-off phase, an acceleration phase and a stabilization phase. These phases are usually illustrated in an S-curve (figure 5). The results from chapter 5 have pointed out that grid operators notice a quickly accelerating energy transition. Although the exact arrival of a phase is difficult to indicate, it is clear that at least the take-off phase has been reached for the energy transition: distributed production on lower grid levels imply a shifting system. The acceleration phase is reached when visible structural changes take place and react to each other and when dominant practices change. It can be argued that the implementation of a solar park or solar panels on rooftops forms a visible structural change and that investments to change the facilitating grid infrastructure is a reaction to this change. Dominant practices could also be considered to be changing, for example with grid operators asking market parties to facilitate flexibility in a functional way and the increasing use of electric vehicles. Regarding the energy transition it is therefore likely that the acceleration phase can be considered as reached.

Transition theory also contains the multi-level perspective, with three levels of social organization: the macro (landscape), meso (regime) and micro (niches) levels. One of the important results regarding these levels is the fact that the electricity grid levels are becoming more and more intertwined because of power flowing in multiple directions. Production is also increasingly taking place in the lower levels of the grid. The entanglement of the grid implies that for the electricity grid the levels of the multi-level perspective are decreasingly separated. However, it can also be argued that this is a change of the regime by pressures from the micro and macro levels as the grid operators are regime actors who face developments such as an increasing use of electric vehicles and environmental goals set by government officials.

6.2. Discussion and recommendations

What do the answers to the sub research questions and the main question mean when looking at the future institutional design of smart grids and for the transnational European electricity network? This section generalizes the outcomes of this thesis and puts them in a wider perspective.

Required adjustments to the electricity grid are not unique for the Netherlands. During the introduction in chapter 1 it has been stressed that the need for adjustments might be higher in the Netherlands because the share of energy from renewables is among the lowest in Europe and that power outages already occur with a small share of energy from renewables. Grid improvement processes do appear to be especially slow in the Netherlands. An important factor in this is the large amount of laws that protect rights. As the Netherlands is a densely populated country, there is a relatively big chance that plans of grid operators to improve the grid have an effect on civilians. This makes public support important for grid operators, perhaps more important for grid operators in countries with a lower population density. The fact that the Netherlands is densely populated and that many protective rights slow down the grid improvement process make the situation a complex one, which is in line with the positioning of the objective that took place in chapter 2. A research on a larger scale that compares countries is recommended to explore the link between population density and grid improvements.

From transition theory literature the idea that regime actors are maintaining institutional barriers was formed. In practice this can be seen identified as well, but it seems to be a result of the historic development of the grid. As the electricity grid has been organized in a conventional way, regime actors are dealing with large magnitudes of power. New players do not seem to be intentionally blocked from entering the energy sector and gaining influence: it simply costs a lot of money to be able to enter the market as a new player, especially when this new player desires to handle substantial amounts of electricity. An (economic) investigation on the economic feasibility of projects such as battery aggregators is recommended to provide more precise information.

Regarding smart grids and the 'smartness' of the current electricity grid, it appeared that key elements of a smart grid are data availability and the possibilities to use this data, mainly in the form of controlling devices. Because those elements are already in order in some parts of the electricity grid, the current grid is to a certain extent 'smart'. To further elaborate on the definition of smart grids and the smartness of a grid, input from more grid operators and non-Dutch grid operators could be useful.

Ultimately it makes sense to think about what to do about the institutional barriers and how adjusted institutional conditions can contribute to the development of a smart electricity system. Bringing incentives to end users is an important step that can be taken. But how many people are willing to change their behavior to use the electricity grid more efficiently? And what exact advantages and disadvantages does this bring for users?
Another area that is worth exploring is the possibility to use curtailment as a solution for congestion. Grid operators would benefit from curtailment, but is this a realistically possible instrument or perhaps an emergency solution? New types of contracts between energy producers and grid operators would be required would likely be required to use curtailment in practice.
Finally, the grid improvement process is slowed down by protective laws. These laws cannot be simply shoved aside and maintaining public support is important for grid operators. A dialogue with involved parties is likely required to come up with a solution for this situation whilst remaining public support and handle in legally allowed ways.

6.3. Reflection

This section will provide a reflection on the theoretical framework and methodology of this thesis, followed by a self-reflection.

After the positioning of the main objective of this thesis the theoretical framework was presented to gain an understanding of the objective. The theoretical framework consists of the Dutch electricity grid, energy transition and transition theory, electricity storage, smart grids and institutions. Transition theory mostly provided the basis for the conceptual model that was presented at the end of chapter 3.

The important role of transition theory in the theoretical framework could have been more clear, rather than transition theory forming a part of a section of chapter 3. A more central role for transition theory would likely have been beneficial for the conceptual model, with more transition theory literature used to form the conceptual model. Instead, chapter 3 started off with the Dutch electricity grid. This made sense to me, as I had limited knowledge about the grid and the grid forms the object that requires improvement. The section on the Dutch electricity grid provided useful background information, but in hindsight it would make more sense to start off with an more in-depth look an transition theory to afterwards connect the Dutch grid to transition theory. The third section of the theoretical framework is the one regarding electricity storage. Electricity storage is important when there is a fluctuating output of electricity. However, I think it would have been better to look at this as a flexibility issue rather than a storage issue. When looking at the topic of electricity storage it is easy to overlook demand response and international connections that can increase flexibility. In other words: there is a need for flexibility rather than a need for just electricity storage. A final comment that I want to make regarding the theoretical framework is on the topic of institutions. I found it difficult to elaborate on the institutional design of the electricity grid as it includes markets, rules and regulations. As I had little knowledge on these topics, an early consultation with experts would have been a good idea.

The methodology of this thesis has been described in chapter 4, after the presentation of the conceptual model. The conceptual model has been used as a tool for further research. Originally I had planned on interviewing a broader selection of actors from the energy sector and to not include literature and desk research in the results of chapter 5. This was before I decided to put emphasis on the institutional design of smart grids.
At first I planned on focusing on blockchain-based smart grids, after getting inspired by reading interesting articles on pilot projects of blockchain-based smart grids. This resulted in a meeting with blockchain developers. After a couple of months the interest in this topic decreased as it became clear that using blockchain on a larger scale in the electricity grid is a pretty futuristic image, resulting in an extremely explorative thesis. After shifting the focus to institutional barriers, inspired by the article of Lammers and Hoppe (2019), the structure and research questions of this thesis changed. Grid operators became the most important targets to interview and parts of the theoretical framework became more relevant for the results-chapter. Fortunately interviews with a regional and the national grid operator could be arranged with no trouble.

In the end the writing process of this thesis took a lot longer than expected, mainly because of the topic change. The decision to change the topic was difficult and the research proposal had been approved months before I made the decision. The change was especially tough as it meant that I had to throw away parts of the thesis that I had been working on. In the end I am happy with the decision though, as the 'new start' allowed me to write the thesis with fewer doubts and less stress. Looking back on the writing process of this thesis, I have learned how important is to gather knowledge early on topics that you have little knowledge about. Especially when performing an explorative research it is valuable to do this as it forms a basis for the rest of the research. For this thesis it meant including a chapter on the positioning of the objective and using the theoretical framework to gain an understanding of the objective.
In hindsight I should have realized earlier that a change of topic was a good idea, rather than to continue struggling with the original topic. This would have lead to a thesis that would have been finished more quickly and likely an improved research strategy.

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Appendix 1: Interview guide Tennet

Full transcription of the interview can be requested from the author at hermanbouma@hotmail.com.

Tennet – Anton Tijdink
Arnhem, 5 augustus 2019

Hartelijk dank dat u wilt meewerken aan mijn onderzoek. Mijn naam is Herman Bouma en ik studeer aan de Rijksuniversiteit Groningen, waar ik de master Environmental and Infrastructure Planning volg. Voor mijn masterscriptie doe ik onderzoek naar ontwikkelingen in het Nederlandse elektriciteitsnet. Door het toenemende aandeel van hernieuwbare elektriciteit is het belangrijk om flexibiliteit te creëren zodat vraag en aanbod in balans kunnen blijven. Er is nog veel onduidelijk hoe het elektriciteitsnet van de toekomst eruit gaat zien, maar de term smart grid wordt vaak genoemd. Het doel van het onderzoek is om inzicht te krijgen in de niet-technische factoren die een smart grid kunnen bevorderen. Het onderzoek richt zich hierbij op institutionele factoren (sturende regels en gebruiken) die een rol spelen in de implementatie van smart grids. De input van Tennet als netbeheerder is hierin erg belangrijk.
Het interview bestaat uit enkele inleidende vragen gevolgd door vragen die bij een bepaald thema horen. Tot slot zullen er enkele afsluitende vragen zijn. Het interview is semi-gestructureerd, wat betekent dat er hier en daar kan worden doorgevraagd.
Voordat we beginnen zal ik toestemming vragen om het gesprek op te nemen. Door het gesprek op te nemen kan ik de focus houden op het gesprek. Het is uiteraard mogelijk om een pauze in te lassen gedurende het interview.
Alle gegevens betreffende het interview kunnen op verzoek worden geanonimiseerd en zullen enkel worden gebruikt voor mijn masterscriptie. U zult van mij een transcriptie van het gesprek toegestuurd krijgen. Uw reactie en toevoegingen op de transcriptie zullen vervolgens worden verwerkt voor een eindversie.

Inleidende vragen
Wat is uw functie binnen Tennet?
Waar heeft u aan gewerkt bij Tennet?
Hoe bent u bij Tennet terecht gekomen?

Vragen per thema:

Het Nederlandse net

1. Het Nederlandse elektriciteitsnet is hiërarchisch opgedeeld, met een transportnet, een koppelnet en een distributienet. Zijn deze lagen in de praktijk compleet van elkaar gescheiden?
   - ➔ Wat vindt u van deze situatie? Brengt dit concrete voor/nadelen met zich mee?
2. Hoe verloopt de samenwerking tussen netbeheerders?
3. Wat zijn volgens u de gevolgen van toenemende decentrale opwekking voor het beheer en onderhoud van het net?

Transitie theorie

4. Wat voor rol spelen netbeheerders in de energietransitie?
5. In de literatuur wordt gesuggereerd dat de 'kleine spelers', de actoren in niches, weinig invloed hebben en weinig worden betrokken bij beleid over het energienetwerk. Hoe kijkt u hier tegenaan?

Energie opslag

6. Opslag van elektrische energie kan op verschillende manieren en op verschillende schaalniveaus. Welke vormen zijn volgens u het meest haalbaar?
   - ➔ Welke factoren spelen hierin een rol?
7. Hoe ziet u de rol van elektrische voertuigen als het gaat om het opslaan van energie?

Smart grids

8. Wanneer is volgens u een 'smart grid' smart? Wat zijn volgens u kenmerken van een smart grid?
9. Wat is volgens u de huidige stand van zaken wat betreft smart grids?
   - ➔ Welke stakeholders zijn belangrijk bij het ontwikkelen van smart grids?
10. Hoe kijkt u aan tegen de veiligheid en betrouwbaarheid van smart grids?
11. Wat zijn volgens u de grootste struikelblokken als het gaat om grootschalige implementatie van smart grids?
    - ➔ Hoe kan deze situatie worden verbeterd?

Institutioneel ontwerp

12. Uit literatuur komt naar voren dat het geheel van regels, marktwerkingen, regulaties en gewoonten aansluit bij het traditionele energienetwerk. Het zou tevens niet aansluiten bij gewenste ontwikkelingen en smart grids. Hoe ervaart u dit?
13. Herkent u deze situatie ook in de internationale markt?
    - ➔ Zou u graag een internationaler beleid zien?
14. Verwacht u een toename van de prijselasticiteit van de vraag naar energie? Zo ja, zou dit stabiliserend werken voor het netwerk?
15. Waar valt, kijkend naar het institutionele ontwerp, de meeste 'winst' te behalen? Heeft u specifieke suggesties?

Afsluiting

Zou u nog graag een bepaald onderwerp willen bespreken?
Heeft u suggesties voor mijn onderzoek en toekomstige onderzoeken over dit onderwerp?

Appendix 2: Interview guide Enexis

Full transcription of the interview can be requested from the author at hermanbouma@hotmail.com.

Enexis – Ton van Cuijk
Den Bosch, 5 augustus 2019

Hartelijk dank dat u wilt meewerken aan mijn onderzoek. Mijn naam is Herman Bouma en ik studeer aan de Rijksuniversiteit Groningen, waar ik de master Environmental and Infrastructure Planning volg. Voor mijn masterscriptie doe ik onderzoek naar ontwikkelingen in het Nederlandse elektriciteitsnet. Door het toenemende aandeel van hernieuwbare elektriciteit is het belangrijk om flexibiliteit te creëren zodat vraag en aanbod in balans kunnen blijven. Er is nog veel onduidelijk hoe het elektriciteitsnet van de toekomst eruit gaat zien, maar de term smart grid wordt vaak genoemd. Het doel van het onderzoek is om inzicht te krijgen in de niet-technische factoren die een smart grid kunnen bevorderen. Het onderzoek richt zich hierbij op institutionele factoren (sturende regels en gebruiken) die een rol spelen in de implementatie van smart grids. De input van Enexis als regionale netbeheerder is hierin erg belangrijk.
Het interview bestaat uit enkele inleidende vragen gevolgd door vragen die bij een bepaald thema horen. Tot slot zullen er enkele afsluitende vragen zijn. Het interview is semi-gestructureerd, wat betekent dat er hier en daar kan worden doorgevraagd.
Voordat we beginnen zal ik toestemming vragen om het gesprek op te nemen. Door het gesprek op te nemen kan ik de focus houden op het gesprek. Het is uiteraard mogelijk om een pauze in te lassen gedurende het interview.
Alle gegevens betreffende het interview kunnen op verzoek worden geanonimiseerd en zullen enkel worden gebruikt voor mijn masterscriptie. U zult van mij een transcriptie van het gesprek toegestuurd krijgen. Uw reactie en toevoegingen op de transcriptie zullen vervolgens worden verwerkt voor een eindversie.

Inleidende vragen
Wat is uw functie binnen Enexis?
Waar heeft u aan gewerkt bij Enexis?
Hoe bent u bij Enexis terecht gekomen?

Vragen per thema:
Het Nederlandse net

1. Het Nederlandse elektriciteitsnet is hiërarchisch opgedeeld, met een transportnet, een koppelnet en een distributienet. Zijn deze lagen in de praktijk compleet van elkaar gescheiden?
   - ➔ Wat vindt u van deze situatie? Brengt dit concrete voor/nadelen met zich mee?
2. Hoe verloopt de samenwerking tussen netbeheerders?
3. Wat zijn volgens u de gevolgen van toenemende decentrale opwekking voor het beheer en onderhoud van het net?

Transitie theorie

4. Wat voor rol spelen netbeheerders in de energietransitie?
5. In de literatuur wordt gesuggereerd dat de ‘kleine spelers’, de actoren in niches, weinig invloed hebben en weinig worden betrokken bij beleid over het energienetwerk. Hoe kijkt u hier tegenaan?

Energie opslag

6. Opslag van elektrische energie kan op verschillende manieren en op verschillende schaalniveaus. Welke vormen zijn volgens u het meest haalbaar?
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    - ➔ Hoe kan deze situatie worden verbeterd?

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12. Uit literatuur komt naar voren dat het geheel van regels, marktwerkingen, regulaties en gewoonten aansluit bij het traditionele energienetwerk. Het zou tevens niet aansluiten bij gewenste ontwikkelingen en smart grids. Hoe ervaart u dit?
13. Verwacht u een toename van de prijselasticiteit van de vraag naar energie? Zo ja, zou dit stabiliserend werken voor het netwerk?
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Afsluiting

Zou u nog graag een bepaald onderwerp willen bespreken?
Heeft u suggesties voor mijn onderzoek en toekomstige onderzoeken over dit onderwerp?