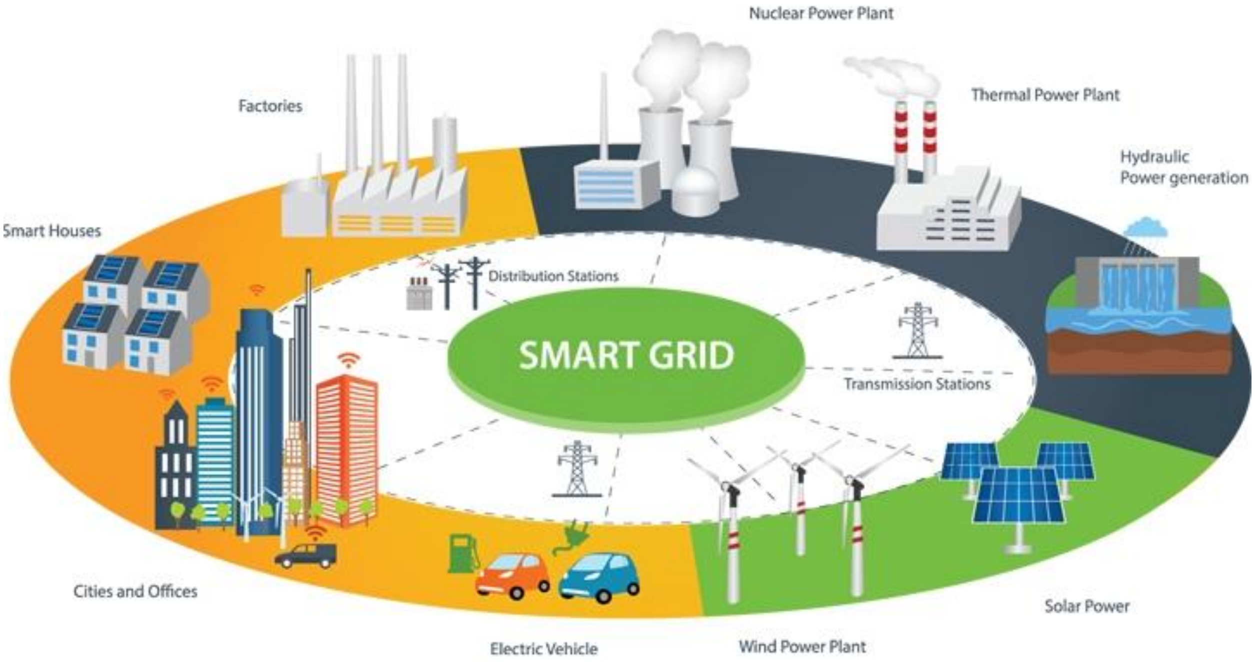
THE FUTURE ELECTRICITY GRID OF THE NETHERLANDS

A SCENARIO STUDY TO OFFER INSIGHTS IN THE UNCERTAINTIES OF THE ELECTRICITY GRID IN THE NETHERLANDS IN 2035-2040



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The future electricity grid in the Netherlands

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Abstract

The Report Limits to Growth in 1972 woke up the world and emphasized the danger of the use of natural resources in the world. One of the subjects which have been subjected to many debates is the greenhouse effect which was among others caused by heavy expulsion of CO_2. Typical natural resources which are used to provide energy are coal, gas and oil and are important contributors to the greenhouse effect.

To put a stop to the greenhouse effect, a change is needed from a system which relies on conventional energy sources to a system which relies on renewables. The shift from an energy system which relies on conventional energy sources to an energy system which relies on renewables is often referred to as "the energy transition". Within the whole energy system to provision of electricity plays an important role, hence the energy transition will also influence the current electricity system. Moreover it has been argued that many electricity grids are on the verge of a radical change.

This is also the case for the electricity grid in the Netherlands, which still relies heavily on conventional energy sources. As renewables penetrate further in the total generated electricity, intermittency problems grow larger. Additional measures are needed to accommodate a high penetration of renewables, but there are still many uncertainties how the electricity grid in the Netherlands should be arranged to accommodate this high penetration of renewables. This research objective of this thesis is to gain insights in the uncertainties which surrounds the electricity grid in the Netherlands. To gain insights in the uncertainties, scenario planning has been selected. Scenario planning can offer insights in uncertainties when it is used as a means. By comparing developed scenarios similarities can be identified. A masterplan consists of developments which appear in all scenarios and contingency plans consist of developments which appear in more than one scenario but not all.

The structure for all scenarios are similar and based on the most promising aspects which have been identified in the theoretical framework and with the data collection. The most promising aspects which have been identified are: Conventional energy sources, Renewables, Energy Storage, Demand Side Management, Interconnectivity and the Plug-In Electric Vehicle.

Four scenarios have been developed based on an empty scenario framework which had two variables: 50% or 80% renewables and a central or decentral oriented electricity grid. The structure of these four scenarios where based on the identified most promising aspects. After the scenarios where developed they were compared to identify potential master and contingency plans.

The results where that no developments appeared in all scenarios, hence no masterplan could be identified. On the other hand nine contingency plans have been recognized. Contingency plans which appeared in three out of four scenarios where: Outsourcing coal power plants and Interconnectivity investments. The other seven contingency plans which appeared in two out of four scenarios where:

(1)Offshore wind parks in both central scenarios, (2)Urban Solar in both decentral scenarios, (3)Mix of renewables in both 80% scenarios, (4)Hydrogen as storing method in both central scenarios, (5)Vehicle to Grid as storing method in both decentral scenarios, (6)Smart Household Machines in both decentral scenarios, (7) DR with fully flexible electricity prices in both decentral scenarios, (8) Investments in upgrading the lokale distributienet in both decentral scenarios and finally (9) a similar penetration of PEV and charging infrastructure in the 80% central and 50% decentral scenario.

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CCS – Carbon Capture and Storage
DR – Demand Response
DSM – Demand Side Management
EE - Energy Efficiency
GW – Gigawatt
Hz – Hertz
Kv – Kilovolt
MW – Megawatt
NSPH – North Sea Power Hub
PEV – Plug-in Electric Vehicle
PV – Photovoltaic
TOU – Time Of Use
TW – Terawatt

1 .Introduction

1.1 Sustainability, Renewables and the Smart Grid

With the publication of the report “The limits to growth” of the Club of Rome in 1972, the interest in sustainability gain momentum. One of the main conclusions of this report was that if mankind would continue to live as they were somewhere within one century the limits of the Earth will be reached. This would cause a sudden and uncontrollable decline in population and industrial capacity (Meadows et al., 1972). This report caused an increase in environmental movements and interest in sustainability. Following this report an increasing awareness of the themes acid rain, ozone depletion, and greenhouse effect started to develop in the 1970’s (Dincer, 2000).

One of the main causes of the greenhouse effect is the emission of CO_2, which causes around 50% of the greenhouse effect (Dincer, 2000). The increase in the use of fossil fuels was a large contributor to the increasing expulsion of CO_2 which consequently raised the interest in alternative sources of energy which did not contribute to a further increase in the emission of CO_2, called renewable energy. In the next decades experiments, exploitation and development of different sources of renewables took place in which solar, wind and water energy are the most common used sources of renewables.

The use of renewables in Europe is further empowered in 2009 by the agreement of all countries in the European Union to generate at least 20% of the energy with renewable energy sources in the year 2020 (Kitzing et al., 2012). For the Netherlands this means a big challenge since only 4,5% of the consumed energy in 2012 is generated by renewable energy sources (Ministerie van Economische Zaken, 2015). At first, simply increasing the construction of renewable energy generators seems a simple solution and a matter of investments but the problem is more complicated than this. This is shown by the adjustment of the goal of the Dutch government from 20% to 14% renewables in the year 2020 (Ministerie van Economische Zaken, 2015). The Dutch government also set a long term goal to repulse 95% of the greenhouses in 2050 (Ministerie van Economische Zaken, 2017). This goal will have consequences for the electricity grid in the Netherlands. In fact, there is a high probability that the electricity grid in the Netherlands is on the verge of a radical change.

Nowadays the daily demand of electricity of the society is to a certain extent predictable. This makes it easy for electricity companies to react on this daily demand. For example, the hour before the society starts going to work an enormous peak in the use of electricity appears and the same peak appears around 5 o'clock when society returns from work. Electricity companies can react on this by intensifying the use of a reactor (e.g. gas/ coal) or by turning a gas or coal reactor off. Renewable energy sources however, are less capable of adapting to society's demand (Potter et al., 2009). On a cloudy day with little wind present, electricity generated by solar and wind generators will not be sufficient to meet the electricity demand. Consequently, major shutdowns of city parts and companies will appear. On the other hand, on a sunny day with a significant amount of wind the output of renewables outweighs the demand side which could either cause a meltdown of high-voltage cables or a temporary output stop of electricity of certain renewable sources. The change towards a sustainable electricity grid is a complex case full of uncertainty. Besides the need of more renewable energy generators an investment in the electricity grid is also needed. Developments in the electricity grid which can respond on supply and demand curves are part of a smarter grid or as the concept in the literature is called “A Smart Grid” (Mohd et al., 2008). These investments in a smarter grid are needed in order to cope with the continually increasing amount of electricity generated by renewable energy sources. Due to the low penetration of renewables (4,5% in 2012) in the Netherlands the development of a Smart Grid is still in its infancy. Many solutions are possible to enable a high penetration of renewables. All these solutions will have different implications for the spatial environment. Because the Netherlands is a densely populated country, these implications will likely be notable by the major part of the population. For example, the construction of wind turbines on land are suffering of heavy resistance in certain regions. Knowing what solutions are possible and what the relation is between the solutions and the spatial environment is an interesting matter for the field of spatial planning.

1.2 Problem definition and research questions

Increasing concerns about environmental issues and greenhouses gasses are putting pressure on the current unsustainable energy system of the Netherlands. Also the electricity industry is still highly dependent on the conventional sources coal and gas. The goal of the Dutch government is to repulse 95% of the greenhouse gas which means that the electricity system in the Netherlands is on the verge of a radical change. Renewables will replace conventional electricity sources and the intermittency of these renewables will have consequences for the electricity system (Albadi & El-Saadany, 2010). The concept which can, among other aspects, manage the intermittency problems of renewables is called a Smart Grid (Mohd et al., 2008). There are however many uncertainties in the development towards a Smart Grid. Just a grasp of possible questions is: “What will be the dominant type of renewables?” and “What will the electric vehicle mean for the future? This all makes it hard to predict how the electricity grid in the Netherlands has developed in a few decades. The goal of this thesis is to gain insights in the uncertainties which surrounds the electricity grid of the Netherlands in 2035-2040. The period 2035-2040 has been selected, because taking in consideration the previous mentioned goal of the Dutch national government, the electricity grid in the Netherlands has probably already been subjected to fundamental changes at this time.

A well-known approach to deal with uncertainties is scenario planning. The goal is not to describe one future which seems the most certain but to develop a set of scenarios. These scenarios combined should cover most possibilities for a Smart Grid in the Netherlands in 2035-2040. Analyzing and comparing these scenarios can give valuable insights in the uncertainties surrounding the future electricity grid in the Netherlands. For the practice of spatial planning in the Netherlands it is especially interesting how these scenarios influence our environment. The goal of this thesis is to develop a masterplan and contingency plans which offer insights in the uncertainty of the future electricity grid of the Netherlands. Scenario planning is used to develop a set of plausible contrasting futures on how the electricity grid of the future can look like in the Netherlands. The scenarios are analyzed and compared to identify similarities and differences between scenarios. Aspects which all scenarios have in common can be used in a masterplan whereas aspects which are present in one, two or three scenarios are part of contingency plans. Based on this the main research question is:

“How can scenario planning offer insight in the uncertainties which go hand in hand with the energy transition and the implication for the electricity grid in the Netherlands in 2035-2040?”

In order to answer the main research question five sub question have been formulated below.

- *What is the energy transition and how does this influence the electricity system in the Netherlands in 2035-2040?*

- *What are promising aspects for the electricity system in the Netherlands in 2035-2040?*

- How can scenario planning offer insight in uncertainties for the electricity system in the Netherlands in 2035-2040?

- What are the implications of the developments in the scenarios for the electricity system in the Netherlands in 2035-2040?

- Which developments do the scenarios have in common and can be used in a masterplan or contingency plans for the electricity system in the Netherlands in 2035-2040?

1.3 Research approach

As mentioned above, the goal of this thesis is to develop a mater and contingency plans for the electricity grid in the Netherlands in 2035-2040. This is done by developing and comparing a set of scenarios. By comparing these scenarios, the differences and similarities in these scenarios can be identified of which the similarities will form a masterplan and contingency plans. Scenario planning is used as an approach to gain insights in the uncertainties, not as a goal. To answer the main research question a three step research approach is used, as shown in figure 1.

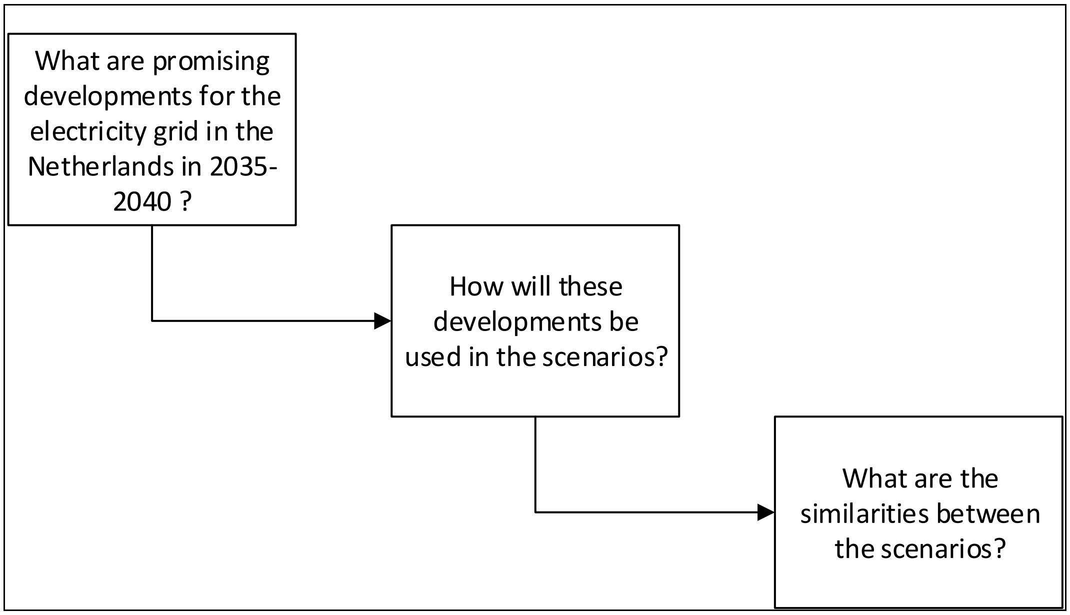


Figure 1: Research approach

<u>What are promising developments for the electricity grid in the Netherlands in 2035-2040?</u>
To determine what the most promising aspects of the future electricity grid are, a literature review is executed. The goal of the review is to identify the most promising aspects in theory. The most mentioned aspects and their characteristics are discussed in chapter 2. Additionally, to identify the most promising aspects of the future electricity grid in the Netherlands, a desk research and interviews are executed.

How will these developments be used in the scenarios?

The next step is to use all the variables identified in the previous step and combine these to develop scenarios. Because the four scenarios have different characteristics one variable will fit better to a particular scenario than others. Four scenarios are developed out of the characteristics (1) central or decentral oriented electricity grid and (2) 50% or 80% penetration of renewables. All the variables where the previous step elaborates on, are in a more or lesser extent, added to these scenarios depending on their fit with the particular scenario. Eventually the four empty scenario frameworks of the scenarios are filled with variables developing four different plausible scenarios. These scenarios cover a range in which the future electricity grid in the Netherlands can develop to.

What are the similarities between the scenarios?

The last step is to compare the developed scenarios in the previous step. The main question of this part is what are the similarities and differences between these scenarios? The similarities can be used in so called "masterplan". A masterplan contains recommendations of what needs to happen no matter how the electricity grid develops. It is also possible that certain aspects will only appear in two or three scenarios. These aspects can be part of contingency plans. The masterplan and contingency plans combined are used to answer the main research question.

1.4 Outline

At the end of chapter two a conceptual framework is developed which is used to seek and answer on the main research question. The conceptual framework consists of a four step approach to develop and compare the scenarios. Ultimately the comparison of the scenarios will answer the main research question. This means that scenario planning is used as a mean to answer the main research question, not as the goal itself. The structure of this thesis consists of 8 chapters and is structured as follows:

Chapter 2 is the theoretical framework which consists of two main parts and the conceptual framework which integrates these two parts. The first part describes how the electricity grid in the Netherlands currently operates and describes relevant aspects for the future electricity grid of the Netherlands (aimed on the period 2035-2040). The description of how the current electricity grid operates is used to give the reader a better understanding of the electricity grid of the Netherlands. The relevant aspects of the future electricity grid of the Netherlands are used to develop the scenarios. Every scenario will address all these aspects which makes them easy for comparison.

The second part of this chapter consists of a description and discussion of relevant theoretical approaches to deal with uncertainties. As the main research question notes, scenario planning will be used as the approach to deal with uncertainties. Scenario planning is not used as a goal but as a mean to deal with the uncertainties surrounding the electricity grid in the Netherlands in 2035-2040. Because the scenarios all have the same structure they are easy to compare and the comparison of the scenarios can offer insights in the uncertainties surrounding the future electricity grid of the Netherlands. By comparing the scenarios master and contingency plans can be identified. The two parts of this chapter will be combined in the conceptual model, which combines scenario planning with the possible relevant aspects of the electricity grid of the Netherlands in 2035-2040.

Chapter 3 also consists of two main parts. The first part will elaborate on the research strategy and data research methods which are used to collect data. The second part is dedicated to the development of a scenario framework and how a masterplan and contingency plans can be extracted out the scenarios.

The collected data is used in chapter 4 and 5 which combined is the execution of the conceptual model developed at the end of chapter 2. The divide in chapter 4 and 5 is made because one part of the conceptual model is used to answer the main research question and the other part of the conceptual model is used in the process to answer the main research question but does not give answer on the main research question. Chapter 4 is dedicated to the process and consists of the basic analysis, context of change and the scenarios. As already mentioned, the scenarios are used as a mean to answer the main research question but not as a goal itself, hence the scenarios are also part of the process of answering the main research question. Chapter 5 is dedicated to the comparison of the scenarios and the masterplan and contingency plans, which can be used to answer the main research question.

Chapter 6 in the conclusion and will answer the main research question. In Chapter 7 the results and conclusion of the thesis will be discussed and chapter 8 is dedicated to a personal reflection and a reflection of the process of writing this thesis.

2. Theoretical framework

This chapter consists of two main parts and the conceptual model. The first part, from section 2.1 to 2.6, is dedicated to the electricity grid in the current situation and in the future.
The second part, from section 2.6 to 2.7.3, is dedicated to theories and approaches which can be used to offer insights in uncertainties in the electricity grid in the Netherlands in 2035-2040. Eventually scenario planning is identified as a suitable approach. In section 2.8 the two parts of the theoretical framework together will be used to develop a conceptual framework to develop scenarios.

2.1 What is the energy transition?

As the main research question mentions the energy transition, this section will elaborate on the energy transition The first part of this section describes what a transition is and the second part will describe how the energy transition influences the future electricity grid in the Netherlands.

Kemp (2010) states that a transition concerns fundamental changes in the functional system of provision and consumption. Further Kemp (2010) states that a transition is rooted in a multidisciplinary approach. This also means that different professions are involved in a transition like; Scientists, historians, politicians. Kemp (2010) categorizes transition thinking into four categories; socio-technical transitions, transition management, social practices and system thinking and reflexive modernization. Despite all categories differ somewhat in their approach they all have one thing in common. They all analyze how a system can undergo fundamental changes towards a completely different system. The change from one system to another can be defined as a transition.
Now the general term transition is clarified the focus can shift to what the energy transition in particular means. How does the energy transition demands fundamental changes in the system? To examine this, the goal of the Dutch national government is examined. The Dutch government attempts to be completely CO_2 neutral in 2050 (Ministerie van Economische Zaken, 2017). On a global scale this means that the expulsion of CO_2 may not exceed the ability of the earth to absorb CO_2 via different ways. Because the energy system of the Netherlands still relies heavily on fossil fuels (coal, gas and petrol), a fundamental change of the system is needed to achieve a CO_2 neutral Dutch society. Renewables will play an important role in the energy transition but due to the intermittency characteristics of renewables, simply replacing coal and gas power plants is not sufficient (Albadi & El-Saadany, 2010). Supply cannot automatically follow demand ,and the intermittency of renewables demand a change of the complete electricity system. The upcoming sections will further elaborate on this.

2.2 What is a Smart Grid?

The first conceptualization of a smarter electricity grid started to appear in the 1980s (Simões et al., 2012). This conceptualization was aimed on a more intelligent interaction on the electricity grid. The goal of a more intelligent electricity grid was to improve the efficiency of the present coal- and gas power plants (Simões et al., 2012). To clarify this, in the U.S.A. 20% of the present power plants are used to only meet the demand of the peak moments, which is about 5% of the time on a yearly base (and are not being active for the other 95% of the time). Because power plants need a huge initial investment the electricity bills of the U.S. household rose dramatically. The Smart Grid was aimed on lowering the peak moments and spreading these peak moments throughout the day and eventually enabling to postpone the

construction of more power plants. Although the concept of Smart Grid was not mentioned in the 1980s, a first idea about the modernization of the electricity grid was born. The need for a modernization of the electricity grid gain more momentum in the upcoming two decades. This was caused by two developments related to the electricity grid. Firstly, after the 1980s the electricity demand rose annually with 2,5% and secondly the integration of renewables in the electricity grid (Gungor et al.,2011).
This eventually caused the introduction of the concept of Smart Grid which was mentioned for the first time by Amin and Wollenberg in 2005 (Simões et al., 2012). Smart Grid, as a reaction on the changing circumstances of the electricity grid, is defined by Gungor et al. (2011) as:

“A smart grid is a modern electric power grid infrastructure for improved efficiency, reliability and safety, with smooth integration of renewable and alternative energy sources, through automated control and modern communications technologies” (pp.1).

As mentioned by Gungor et al. (2011), efficiency is one of the drivers of the development of a smart grid but only covers a small part of the benefits. Another important aspect is that a smart grid enables a smooth integration of renewable energy sources which can be a solution to the possible mismatch of supply and demand of renewables. Moreover, a Smart Grid seems especially suited for the energy transition as it can smoothly integrate renewable energy sources in the electricity grid. Also a smart grid entails “automated control and modern communications technologies”. The idea of these technologies is that it manages the flows of electricity in the electricity grid automatically by responding on different data flows on certain places in a smart grid.

Another definition of smart grid is given by Fang et al. (2012)

“More specifically, a Smart Grid can be regarded as an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable” (pp. 944).

This definition adds up to the definition of Gungor et al. (2011) by describing that automated control should work by using two-way cyber communication technologies throughout the whole electricity grid. An important difference between the two definition is that the definition of Gungor et al. (2011) only considers the grid itself as part of the Smart Grid, where the Smart Grid smoothly integrates renewables and alternative energy sources whereas Fang et al. (2012) mentioned the whole electricity system as being part of the Smart Grid, from electricity generation to consumption.
The definition of Smart Grid used in this thesis will be a combination of these two definition and will be:

“A Smart Grid is a modern electricity grid system which entails the whole electricity system, from generation to consumption, and uses two-way cyber communication technologies to smoothly integrate renewable energy and achieve a more clear, safe, reliable, resilient, efficient and sustainable way of managing supply and demand of electricity”.

Combining the two definitions adds up the explicit integration of renewables in a Smart Grid in combination with considering Smart Grid as the whole electricity system, from generation to consumption, not just the electricity cable infrastructure. The cyber communication technologies are needed to facilitate all kind of possible applications which are described in section 2.4.

2.3 The current electricity grid in the Netherlands

This section aims at describing how the current electricity grid is arranged in the Netherlands. This is needed because the costs of the construction of a new electricity grid is enormous and does not seems to be a solution. The principals of a Smart Grid have the be more or less integrated within the current electricity grid.

The current electricity grid can be divided in two main functions. Firstly, the transport function and secondly the distribution function. As the name already suggests the transport function is mainly mentioned to transport electricity from one place to another and is mostly above ground. The transport grid is further divided into two separate grids called the “koppelnet” and “transport net”. The koppelnet is shown as the red ring in the middle in figure 2. The koppelnet has two main functions. Firstly, it is internationally connected to different neighboring electricity grids. The electricity which is purchased from Germany is transported via this grid. Secondly it transports the electricity generated by power plants which operate on a national level. These are the power plants which can generate the most electricity. The characteristic which distinguishes all the different grids from each other is the capacity which can be transport through the grid and the capacity of electricity generated by the power plants. In case of the koppelnet the transport capacity is > 1000MW and the generation unit is >500MW. The generated amount on this part of the grid is still unworkable and no end-users are connected to this part of the grid. An example of a production unit which is active on this grid is the power plant at the Eemsdelta of RWE which can generate up to 780MW.
The second part of the transport function is the “transportnet” which is mainly above the surface. The transport grid operates between the koppelnet and the distribution function and is shown as the orange ring in figure 2. The transportnet operates on the regional level, or in the Netherlands on the provincial level, which have a particular regional grid operator. On the regional level the unit of electricity is downgraded to >100MW to get it closer to a workable unit. On the transportnet different kind of electricity generation take place. Regional power plants generate a unit of 10-500MW on this part of the grid and also wind turbine parks and other green energy sources with >10MW generating capacity deliver electricity on this part of the grid. The first end-users appear on this part of the grid. This are the large, high consuming electricity industries which need at least 10MW.
The second function, as already mentioned, is the distribution function. The distribution function is also divided into two grids. Firstly, the “regionale distributienet” and secondly the “lokale distributienet”. The distribution function of the grid has the main goal to deliver electricity to end-users. The so called “groot verbruikers” which can be loosely translated to high quantity users are connected to the regionale distributienet. The usage of end-users of electricity are within the 0,3MW - 10MW. The unit of electricity in this part of the grid is <100MW. This enables for example the possibility to connect single wind turbines to

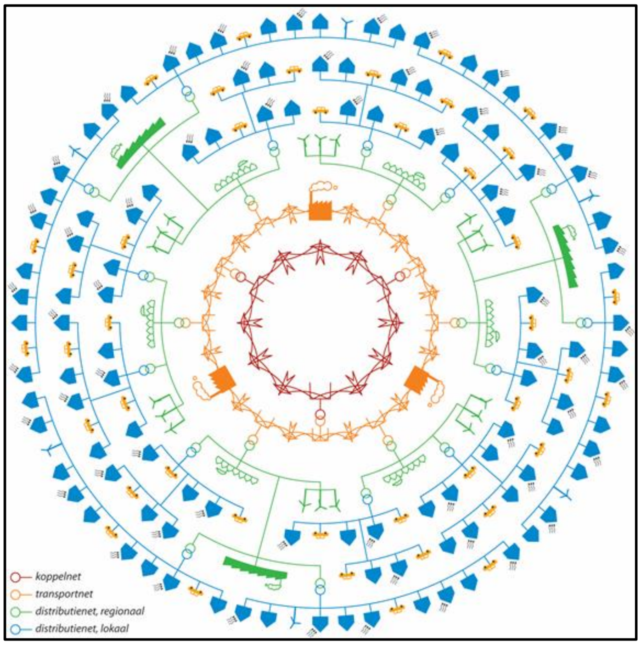


Figure 2: The electricity grid and its different parts
Source: https://phasetophase.nl/

the grid. Wind turbines can currently generate up to 8 MW depending on this size of the wind turbine and it is expected that it goes up to 10 MW on shore and 20 MW off shore (Nieuwenhuis, 2015). The third ring (green) from the inside resembles the regionale distributienet in figure 2.

The last part of the electricity grid is the lokale distributienet. This part of the grid has the lowest unit of electricity which is < 1 MW and is connected to the regional distribution grid. On this part of the grid individual households and smaller companies are connected and is shown in figure 2 as the outer three rings (blue). Solar panels on individual houses are increasingly more common in this part of the grid hence generating electricity also starts to appear on the most decentralized part of the grid. Because generation is done on both the most centralized and the most decentralized part of the grid it gives a strong argument why a two-way communication system, like the Smart Grid is needed in order to manage the electricity flow.

The divide into different parts of the grid is needed because at a higher voltage the electricity grid can transport more electricity than at a lower voltage. For the electricity grid in the Netherlands this means that the koppelnet uses 220/380 kV, the transportnet uses 50/100/110 kV, the regional distribution grid uses 3-25 kV and the local distribution net uses 0,4 kV.

Ultimately the supply and demand always have to be in balance to achieve a stable electricity grid. The grid in the Netherlands is ought stable when it fluctuates between 49.8 Hz - 50.2 Hz with 50Hz being the ideal frequency.

In order to build a better understanding an analogy between the electricity grid and the road infrastructure of a country can be made. Both networks consist of an infrastructure which only has the function of transporting a certain flow. For the road infrastructure network these are the highways and for the electricity infrastructure these are “koppelnet” and the “transportnet”. The goal of these parts of the network is the capability of transporting a large amount of traffic. An overload of traffic can have severe influence on the electricity grid with a meltdown of the cable whereas the consequences for the road infrastructure are less severe. It will suffer from a temporary traffic jam.

As the capacity of the infrastructure drops it becomes more useful for the surrounding area. On the road infrastructure network the first houses start to appear on the provincial road. This is also the case for the electricity grid which has its first end users on the transportnet, the high consuming electricity industries. The capacity of these parts of the network are downgraded compared to the above mentioned parts and more aimed on the end users.

As the capacity is downgraded further it becomes increasingly more suited for end-users needs. The lokale disitributienet is aimed at providing a product which is aimed at individual households. It delivers the right voltage so that household machines do not get an overload of electricity. The lokale distributienet can be typically compared to a neighborhood street where most houses are connected to. This street meets the need of a neighborhood street as the traffic drives slowly and the streets have little traffic capacity compared to the highways.

There is also a difference in the analogy between the road network and the electricity network. The conventional generators are suited for the higher capacity parts of the electricity grid, the electricity grid is a centrally organized network where the flow is generated on a central level. The traffic of a road infrastructure appears on the most local part of the network and goes via the more centralized part of the network towards another more local part of the network. This makes the road infrastructure network a more decentralized network. Focusing on renewables this will also be more the case for the electricity grid as they are mainly connected to the more decentral part of the electricity grid but currently most electricity grids still heavily rely on centrally generated electricity by conventional energy sources.

A last notable development is when more electricity is generated on a decentral level more and smaller generators will be present to meet the electricity demand. Every household can become a supplier if solar panels are installed. This in combination with generating electricity on every part of the grid makes the electricity grid much more complex than the road infrastructure network. As this complexity increases a smarter grid is more suited to accommodate these developments. Every household can become a consumer and supplier, or as referred to in literature, prosumers (Grijalva & Tariq, 2011).

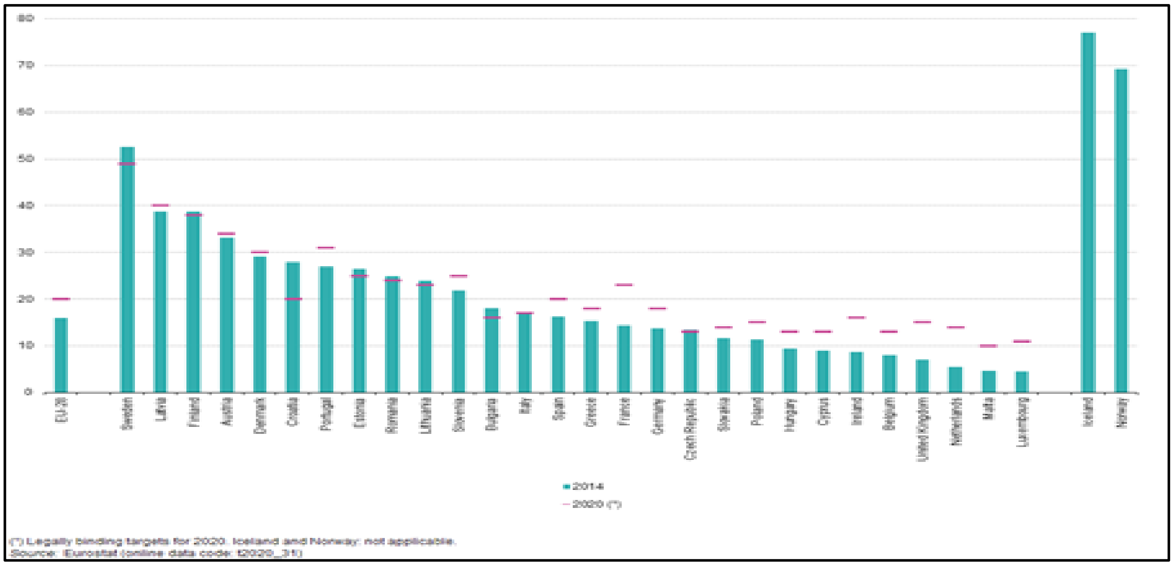
2.4 Applications in a Smarter Grid

This section is aimed at identifying and describing the most promising aspect for the future electricity grid. The aspects which have been identified are consecutively: Conventional energy sources, Renewables, Energy storage, DSM and the PEV. The PEV is discussed separately because it can be used in different ways and can have a different effect on the electricity grid. Below a more detailed description of the characteristics of these aspects are given. For the scenarios, which are developed later on, these aspects form the basic structure of every scenario but will be present differently in all scenarios.

2.4.1 Conventional energy sources and CCS

Conventional energy sources are oil, gas and coal (Bose, 2016)**.** Of these sources gas and coal power plants are the conventional generators which mostly feed the electricity grid. Both coal and gas power plants are needed in order to keep the grid reliable. A well matched combination of gas and coal generators can supply the electricity which is needed at any time of the day. Despite both coal and gas power plants are needed to keep the grid reliable, the ratio per country can differ significantly. In the Netherlands for example, the electricity generated with gas turbines in the period of 2012 - 2013 was around 65% of the total generated electricity with fossil fuels (van Wezel, 2015). In the neighboring country Germany, the generated electricity with gas was approximately 18% of the total fossil fuel generated electricity in 2014 (Metelec, 2017). The remaining part was generated with coal and lignite (brown coal). As in the Netherlands and Germany the electricity grid in many European countries still relies heavily on conventional energy sources. Figure 3 shows electricity generated with renewable energy sources as a percentage of the total generated electricity per country in Europe. This figure illustrates less than half of the countries have a penetration of 20% or more. The transition towards an electricity grid which is mainly fed by renewable energy is still in its infancy in many countries. Consequently, conventional electricity sources will play a major role in the transition towards a sustainable electricity grid.

Though conventional generators expulse CO_2 there is an option to manage the energy transition with these conventional generators. Carbon Capture and Storage (CCS) is a concept which captures the expulsed CO_2. Haszeldine (2009) describes three different possibilities of capturing CO_2; Pre combustion capture, Post combustion capture and Oxy fuel combustion. These three types of CCS both have their



(*) Legally binding targets for 2020. Iceland and Norway: not applicable.
Source: Eurostat (online data code: t2020_31)

Figure 3: Renewables in Europe. Source: http://ec.europa.eu

advantages and disadvantages but all essentially capture CO_2. When the CO_2 is extracted it has to be transported and stored. The transportation is traditionally done with pipelines (Haszeldine (2009). These pipelines transport the CO_2 under high pressure. More recently the transportation of CO_2 can also be done by ship or tanker truck (McCoy & Ruben, 2008). To transport CO_2 in large quantities pipelines are usually economically the most viable option. Only when CO_2 has to be transported over large distances over sea, transport via ships can economically be more beneficial than pipelines (Pires et al., 2011)

The storage of CO_2 is done in different places deep underneath the ground. Storing however cannot be done on any place. Certain geographical characteristics are needed to keep the CO_2 on the place where it is stored. Otherwise it can leak through the earth and eventually end up in the atmosphere (exactly what CCS is trying to avoid). Typical places in which CO_2 can be stored are empty oil- and gas fields, in saline formations or in space of sedimentary rocks (Haszeldine, 2009). It should not be confused that these empty gas and oil fields are empty spaces in which CO_2 can just flow in. CO_2 can only be stored here when its stored under high pressure. This makes the storage of CO_2 a potentially dangerous process if not carefully managed and financially expensive (Haszeldine, 2009). Also the high initial construction costs form a barrier which could impede the storage of CO_2 (Haszeldine, 2009). Figure 4 is a visualized representation of how a CCS system operates.

CCS is considered as middle term solution in the energy transition towards a CO_2 neutral energy system which gives the energy system a 50-year extra period to make the transition towards a CO_2 neutral energy system (Hazseldine, 2009). However, it is discussable if CCS contributes to the energy transition or not as it does not decrease the expulsion of CO_2 but only stores the CO_2 on location where it does not re-enter the atmosphere (which does contribute to the reduction of the greenhouse effect).

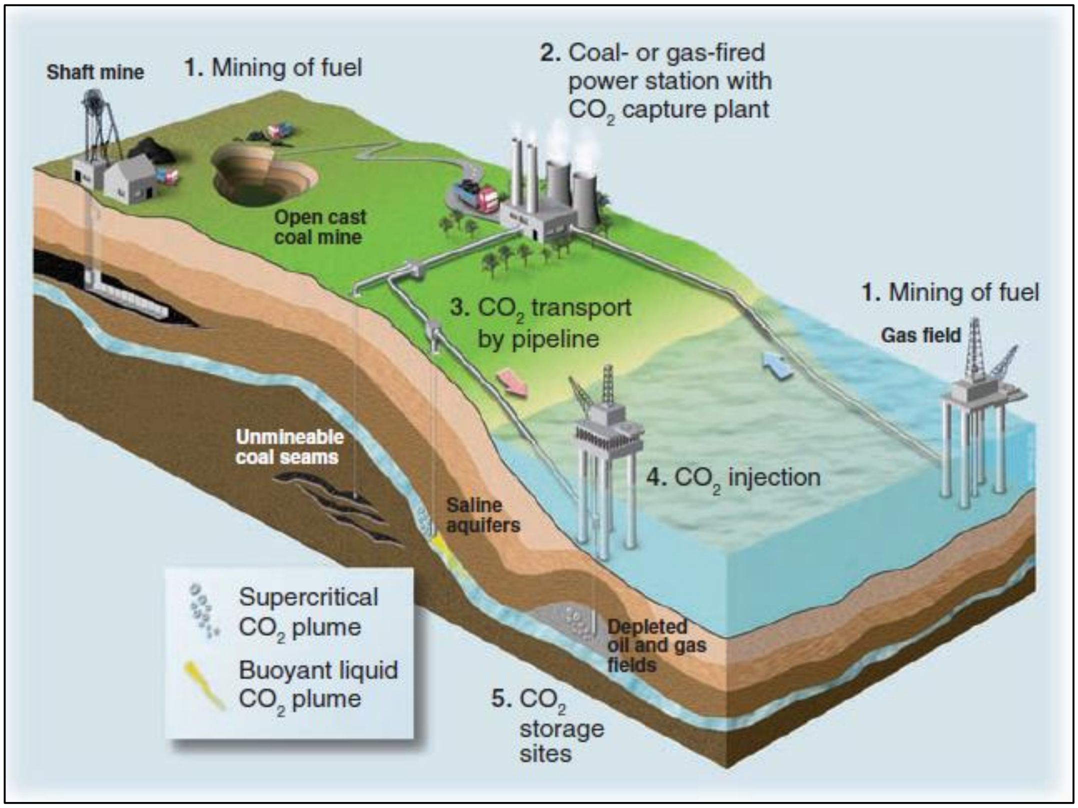


Figure 4: CCS. Source: Haszeldine (2009)

2.4.2 Renewables

Renewables contribute increasingly more to the total generated electricity. However, electricity generated by renewables have two implications for the electricity grid. Firstly, the conventional generated electricity is done centrally with large coal and gas power plants. Electricity generated with renewable energy sources are generated on a smaller scale on a different part of the electricity grid. Secondly the electricity generated with renewables is not as much controllable as the conventional gas and coal generated electricity, due to the dependency on the weather. The thesis will include solar and wind energy as the two types of renewables because these renewable sources show the most potential (Saber & Venayagamoorthy, 2012, Liserre et al., 2010, Mwasilu et al., 2014). The characteristics of these types of renewables will be described first and following the scale on which the renewables are implemented and finally the penetration level of renewables and the effect on the reliability of the grid will be addressed.

Hydro power plants will not be described as it is expected that in a flat country as the Netherlands, hydro energy cannot be applied. Describing the characteristics of solar and wind energy will give insight for the application in the later developed scenarios.

Solar Photovoltaic (PV)

Generating solar electricity is dependent on the radiation of the sun. This makes solar energy vulnerable to weather conditions. On a cloudy day solar panels will generate less electricity than on a sunny day. The electricity generated by solar panels is mostly done in the afternoon. Figure 5 shows the output of solar pv on a summer day in Germany. Though the amounts are not comparable with the Netherlands the arch itself is applicable to the Netherlands. Figure 5 clearly shows how that the generation peak is between 11:00 AM - 3:00 PM. It also shows the time of the day electricity is not generated by the solar panels. Taking into account the extensive use of electricity in different societies, relying fully on solar electricity without the possibility of using the electricity on moments it is not generated, is not an option. Streetlights for example could not be used throughout the night, even simple lightning in a household would not work. Figure 6 shows how this generation fits into the total generation throughout the day. On the peak moments solar pv supplies around 50% of the total electricity demand in Germany but it also causes the generated electricity to exceed the total demand. To avoid overloading during these peak moments electricity had to be transported to neighboring countries. Increasing solar pv electricity even further will mean that on these moments more electricity has to be transported due to the inflexibility of the grid.

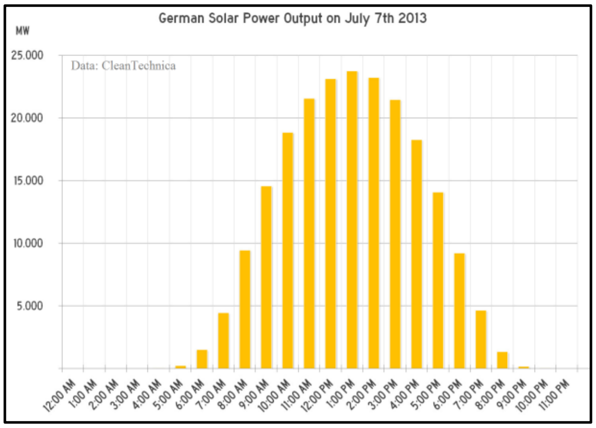


Figure 5: Solar PV output in Germany
Source: https://www.evwind.es

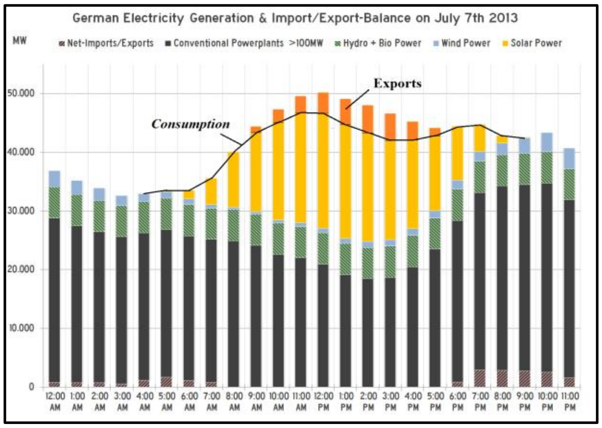


Figure 6: Solar PV output compared to total output in Germany: Source: https://www.evwind.es

During this year only 5,7% of the total electricity was supplied by solar pv (Andrews, 2014). Also note that electricity is only supplied between 6:00 AM - 8:00 PM. On the other hours of the day electricity had to be supplied by other sources which clarifies the mismatch between supply and demand.

Besides the daily profile of solar pv generation there is also a significant difference in the seasonal supply of solar pv electricity. The difference in output between the seasons differs per area. Figure 7 shows how this differs per region in the EU. With the south of Spain only differing around 10% of the average annual generated solar energy and in Norway as much as 80% of the annual average. The Netherlands lies in between these percentages with a difference of 40%. The summer is the season in which the electricity output of solar pv is the highest and the winter is the season in which the output is the lowest (Šúri et al., 2007). This annual fluctuation is also a mismatch in supply and

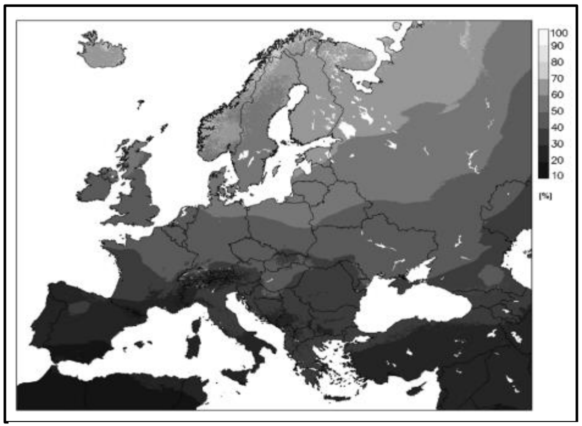


Figure 7: Solar PV annual fluctuation in Europe
Source: Šúri et al., (2007)

demand because in the winter the electricity demand in the Netherlands is the highest due to heating and lighting (van Oirsouw, 2012).

The higher the penetration level of solar pv is the more it can also accommodate the electricity demand in the winter period but consequently also creates a higher surplus in the summer. Another aim can be the economic viability in which solar pv accommodates the maximum amount of electricity without stressing the electricity grid. However, the grid of Germany (and its flexibility) has shown that at a penetration of 5,7% electricity generated by solar pv already stresses the electricity grid because the supply and demand did not match. Concluding it can be stated that integrating a large amount of electricity generated by solar pv in the grid is a complex matter as the supply and demand of electricity does not always match on different time frames.

Wind turbines

Electricity generated by wind turbines is dependent on wind, hence has its own characteristics. The characteristics can differ on different time scales and can also differ per region. Albadi & El-Saadany (2010) divide these fluctuations in five different time scales called annual, seasonal, synoptic, diurnal and turbulences. These fluctuations on different time scales can stress the stability of the electricity grid and makes an integration of a high penetration of electricity generated by wind turbines complex. Each type of fluctuation has its own predictability and solutions to keep the grid stable. The annual fluctuation is not predictable but the maximum annual standard deviation of a period of 20 years is 10% (Ackermann, 2005). Due to this low standard deviation the annual fluctuation of wind energy is not a big problem for the stability of the electricity grid.

The seasonal fluctuation is more predictable but fluctuates more than the annual fluctuation. Figure 8 shows the average wind speed per month calculated over the period 1981 - 2010. The difference between the month with the highest (January) and the lowest (August) wind speed is approximately 32% in Ukkel (near Brussels). This is a much bigger difference than the annual variation in wind speed. The synoptic, diurnal and turbulence peaks appear in a much shorter period of time. The synoptic peak moments typically correlate with the weekly weather systems passing by, the diurnal typically correlates with the daily weather and the turbulence peaks appear on a timescale of minutes as shown in figure 9. The predictability of the synoptic weather is only accurately predictable a few days ahead whereas the daily weather is predictable and the turbulences are not predictable at all (Albadi & El-Saadany, 2010). This can have a significant impact on the grid and this impact will increase when there is a higher penetration of wind energy.

The impact of the synoptic and diurnal fluctuation on the stability of the electricity grid can be reduced by a wider geographical dispersion of wind turbines (Albadi & El-Saadany, 2010). A research on the Ontario

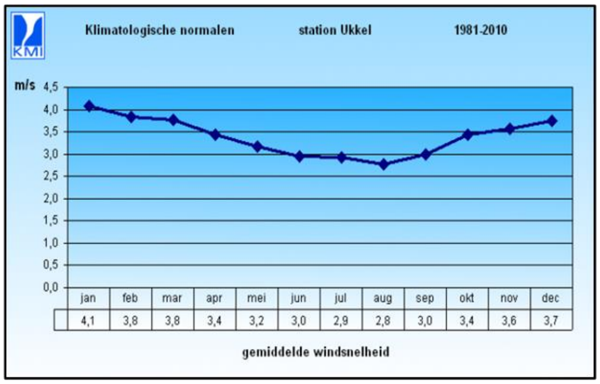


Figure 8: Average momtly wind speed in Ukkel (Belgium). Source: https://www.meteo.be

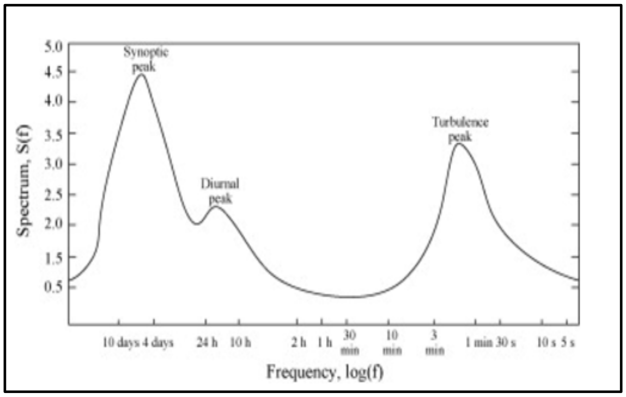


Figure 9: Synoptic, diurnal and peaks. Source: Albadi & El-Saadany, (2010)

wind turbine farms has shown that the variability can drop between 60% - 70% if the wind turbines are geographically more dispersed compared to a single larger wind farm on a smaller area, for 10 minutes and 1-hour data (Truewind, 2005). Consequently, a wider geographical dispersion makes it easier to predict the output of the wind turbines in a larger area.

The decision of a maximum spreading of wind turbines seems an easy one but there are however reasons of not fully spreading the wind turbines throughout the area. One of these reasons is that a wider spreading of wind turbines also means there is more infrastructure needed to transport the generated electricity. Secondly a wider geographical dispersion can mean that an optimal use of the geographical differentiation in wind speed cannot be met. Figure 10 shows the annual average wind speed in the Netherlands on an altitude of 100 meters measured between the period of 1981 - 2010. This figure clearly shows the higher wind speed near the shore of the Netherlands with an average wind speed of > 9 m/s whereas some parts further away from the shore show an annual average wind speed of <6 m/s. Economic optimization of wind turbines in the Netherlands would mean a higher concentration of wind turbines near the shore would be beneficial. With the construction of future wind farms in the Netherlands the consideration between a flattening of the peak output and the economic optimization can be an important factor on the area a wind park will be constructed. The seasonal profile of wind energy matches better with the seasonal demand side compared to the generation of solar panels. The geographical dispersion however is a debatable aspect. Spreading the wind turbines is a way of absorbing turbulence peaks but an economic efficient wind turbine has to be placed on areas where wind is the most present. And despite the seasonal profile is a better match with the demand side, this does not mean intermittency issues cannot occur.

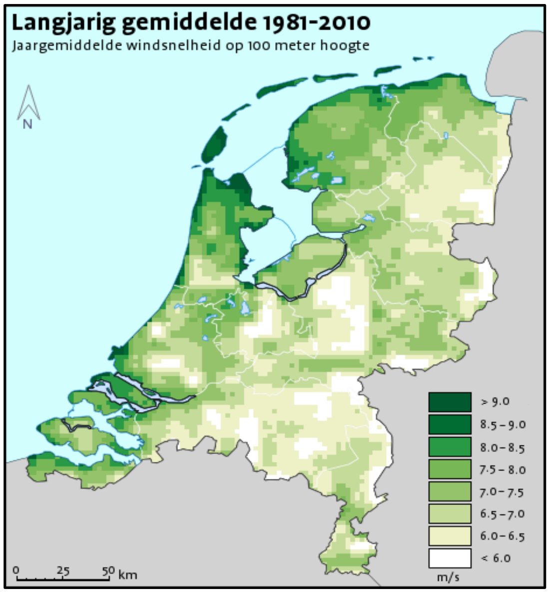


Figure 10: Average wind speed in the Netherlands
Source: www.klimaatatlas.nl

Different scale

The electricity generated by renewables takes place on a different level than the generation of fossil fuel electricity. Whereas the output of conventional generators take place on a central level the output of renewables take place on a more decentral level. The electricity generated with and coal power plants takes place on the “koppelnet” and the “transportnet”. Generated electricity with of renewables takes place mostly on the “regional- and local distributienet”. Shifting from fossil fuels to renewables will consequently influence the investments needed in the particular parts of the grid. Between different types of renewables (wind and solar) there are also some differences concerning the part of the grid is it implemented. Individual wind turbines can produce up to 10 MW per turbine. This means wind turbines can be connected to the grid on the “regionale distributienet”. Besides the individual connection of wind turbines there is also a possibility to construct wind turbines parks. In general, these wind turbine parks match the capacity of the “transportnet” (van Oirsouw, 2012).

The electricity generated with solar pv can take place by individual solar panels which means every household is capable of producing electricity with solar panels by for example placing solar panels on the roof top. Electricity generated with individual solar panels take place on the “lokale distributienet”. Another possibility for photovoltaic electricity is the construction of solar panel parks. Generally, the output of these parks matches with the capacity of the “regionale distributienet”.

Penetration level vs reliability

Renewables are depended on solar radiation and wind. Consequently, renewables cannot adapt to the daily demand of society. This can have severe consequences for the reliability of the electricity grid. In general, there can be stated that the reliability of an electricity grid decreases as renewable energy gets a larger share of the total generated electricity. Initially the penetration of renewables on an electricity grid will have little influence on the performance of the grid. The intermittency of renewables can be absorbed by conventional electricity generators. As renewables penetrate further in the daily electricity production the possibility of a blackout rises. When the penetration of renewables reaches around 30% of the total generated electricity, the influence on the electricity supply reaches a tipping point in which the conventional electricity generators cannot compensate the fluctuating electricity generated with renewables (Crabtree et al., 2011; Hazseldine, 2009). At this moment additional methods are needed to keep the grid in balance. Different types of methods to keep the electricity grid in balance will be discussed in section 2.4.3.

Grid performance

This section will discuss which factors influence the performance of an electricity grid. As argued in the previous section, conventional generators can absorb the intermittency of renewables until approximately 30% of the electricity is generated with renewables. Denholm & Hand (2011) elaborate on the phase after 30% penetration of renewables have been reached. In their research they describe (1) system flexibility, (2) mix of renewables, (3) percentage of penetration as important variables influencing the performance of the electricity grid. Certain combinations of these variables and their economic value are described. Firstly, the system flexibility which is described as:

"*System flexibility can be described as the general characteristic of the ability of the aggregated set of generators to respond to the variation and uncertainty in net load. At extremely high penetration of VG, a key element of system flexibility is the ability of baseload generators, as well as generators providing operating reserves, to reduce output to very low levels while maintaining system reliability" (Denholm & Hand 2011, p. 1819).*

Because electricity generated by renewables relies on the weather conditions, the output of renewable electricity is uncertain. A more flexible electricity grid can absorb these shocks by using the reserves. These reserves are different types of generators which can increase or lower their output dependent on the electricity demand (Denholm & Hand, 2011). This not only means that these generators should be able to increase their generation on moments electricity generated with renewables is low but also decrease their output on moments the output of renewables is high. If for example a generator can only decrease the output by 20%, a peak of renewable electricity can stress the electricity grid or the renewable electricity has to be temporarily curtailed. In general, there can be stated that a more flexible electricity grid can accommodate a higher penetration of renewables. This can be clarified by Figure 11. As previously mentioned Germany had to export some of the electricity to avoid an overloading over their electricity grid. This was avoidable when conventional electricity sources (grey color) would be more flexible. If the German electricity system was capable of lowering the output of conventional electricity sources even more, the export of electricity would not be necessary and the contribution of renewable energy to the total generated electricity would have been higher.

The second variable is the mix of renewables. The mix of renewables is an important factor because solar and wind both have a different generation profile throughout the day and year. On a daily base the generation of wind energy can differ as much as 100% and the generation of solar energy can differ up to 70% (Crabtree et al., 2011). Figure 11 clearly shows how that the output peak of solar is between 11:00

AM - 3:00 PM. Figure 11 shows how this output fits into the total generated electricity throughout the day. On the peaking moments solar pv supplies around 50% of the total electricity demand in Germany but it also causes the output to exceed the total demand. Finding the right ratio of renewables which suits the electricity demand on all time scales can be of much value for the electricity grid. This was also noted by Denholm & Hand (2011). They conducted a research on what the influence of different mixes of renewables would be on the electricity grid. Figure 12 summarizes their findings of which a few important conclusions can be drawn. Despite the outcome is based on the Texas region it nevertheless shows a general tendency of favorable ratios of solar/wind.

The first conclusion which can be drawn is that a solar dominating scenario shows a larger curtailment rate than the wind dominating scenarios. Even the 100% wind scenario has a lower curtailment rate than the 60% solar/40% wind scenario. The output pattern of wind energy matches better to the daily demand than the solar output pattern (Denholm & Hand, 2011).

The second conclusion which can be drawn is that, although the wind output pattern is a better match to the daily demand pattern, focusing fully on wind energy is not the most efficient way either. The most efficient ratio of solar/wind generated electricity is between the 30% solar/70% wind and 20% solar/80% wind ratio.

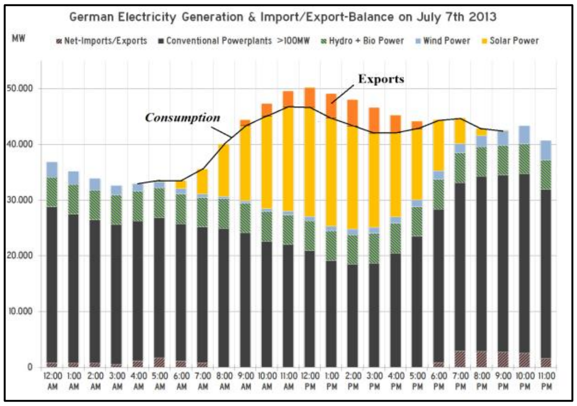


Figure 11: Solar PV output compared to total output in Germany: Source: https://www.evwind.es

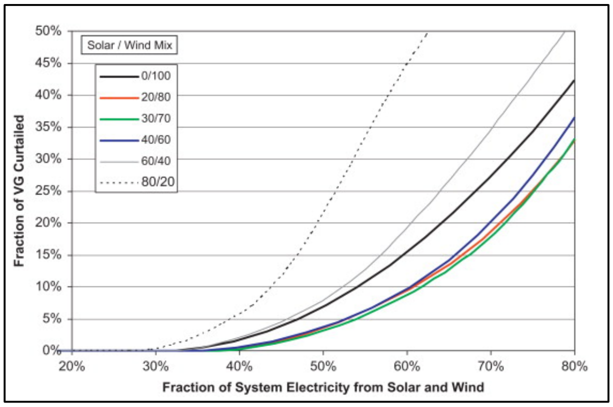


Figure 12: Curtailment rate at different ratios of solar and wind Source: Denholm & Hand, 2011

The third conclusion which can be drawn from this figure is also the third aspects of Denholm & Hand (2011), which is the penetration of renewables. The larger the share of renewables is of the total electricity out the larger the curtailment rates. Especially the disadvantages ratios show a steep curtailment line. In the favorable ratios the curtailment rate is still below 5% at 50% penetration of renewables but after this the curtailment rate also raises drastically with a curtailment rate of around 33% at a penetration of 80% renewables. The ratios in figure 12 are based on a 100% flexibility of conventional generators which makes the outcome of this figure the most favorable. To avoid large curtailment rates additional measures have to be taken at a high penetration of renewables. These additional measures are described in the next section and are all used as methods to keep the grid stable.

2.4.3 Methods for balancing the electricity grid

When the renewables penetrate more in the electricity net the intermittency of renewables become an increasing disturbing factor. At around 30% penetration of renewables the conventional energy sources cannot cope the intermittency of renewables (Crabtree et al., 2011). At this moment it becomes an increasingly important aspect to manage the supply and demand side of electricity. This section elaborates on different ways of managing supply and demand. In this thesis two means of managing supply and demand will be discussed. Firstly, the section will address the storage of energy. This aspect is aimed on managing the supply side of the electricity grid by storing electricity on moments electricity is abundant and feeding this electricity to the grid on moments electricity is scarce. Secondly the aspects of demand side management will be addressed. There are various ways of demand side management which will be discussed after the storage of electricity.

Energy storage

Electricity itself is difficult to store but there are various techniques to convert electricity in different types of energy. Evans et al. (2012) mention mechanical, thermal and chemical energy storage as a possibility to convert electricity in a different type of energy. In this thesis energy storage refers to all the different storing techniques in which (abundant) electricity can be converted in different sources of energy.

Storing energy is a much mentioned solution for balancing the electricity grid by managing the supply side (Mohd et al., 2008, Wade et al., 2010, Sechilariu et al., 2013, Koutsopoulos et al., 2011). The development of storing electricity is still in its primal phase and the methods of storing are abundant. The amount of storage needed to achieve a certain percentage of renewable penetration is closely interlinked with the flexibility of the grid. If a grid is more flexible it needs less storage capacity due to the ability of the conventional energy sources to balance the electricity supply with the demand. This section will categorize possible ways of storing energy by connecting them to different parts of the grid, but will not address the precise characteristics of them. The reason for this is that most energy storage methods are still in its primal phase (Luo et al., 2015). Instead the categorization of Crabtree et al. (2011) will be used. They categorize storage methods into (1) low capacity but fast response suited for seconds till a few hours respond and (2) high capacity but slow response for changes over one or more days. The categorization of Crabtree et al. (2011) does not describe seasonal storage. Seasonal storage will be described after the categorization of Crabtree et al. (2011) is discussed.

A method of storing energy which is the most established and developed way of storing energy on the scale of the grid is pumped-hydro energy storage (PHES). An example of this is the Hoover dam on the border of Nevada and Arizona. For effectively storing pumped-hydro energy however a high difference in altitude is needed. Due to the geographical characteristics of the Netherlands this method is not an option and will not be considered as a way of storing energy.

A possible way of storing in energy is called compressed air energy storage (CAES). As the name suggests CAES is a system in which (redundant) electricity is used to store air under high pressure in a storage device. When electricity gets scarce the compressed air is released to generate electricity. This compressed air can be stored in a salt or rock cavern underneath the grown via a set of devices and can be released and turned into electricity via another set of devices (Kim et al., 2011). Consequently, a salt or rock cavern need to be present in order to construct an operating CAES. Another possibility for storing CAES energy is by man-made air vessels. The size of these vessels are however much smaller than the storage in salt or rock caverns (Kim et al., 2011). CAES is a typical energy storage system which suits to a high capacity with a slow response (Crabtree, 2011). CAES can store between 50MW and 1 GW which means it matches with the “koppelnet” and the “transportnet” (Crabtree et al., 2011).

Another way of storing energy is in different types of batteries. The advantage of batteries is that it is not restricted to locations with certain geographical characteristics. Crabtree et al. (2011) describe lead acid batteries, sodium sulfur batteries, flow batteries, vanadium redox flow batteries and zinc bromide flow batteries as possible solutions for battery storage.

The sodium sulfur batteries are the most mature type of battery and is already used on a small scale in the U.S. and Japan. These batteries need a temperature of around 300 °C to keep the materials molten Crabtree et al. (2011). Though the sodium sulfur batteries are in theory applicable anywhere the required temperature makes it unwanted in residential areas. The sodium sulfur battery has the storage potential between 200kw and 4 MW (Crabtree et al., 2011). This matches with the “regionale distributienet”. The Vanadium Redox Flow battery is another new type of battery which already showed its value for the grid within the range of 800 Kw - 1,5 MW. This storage capacity matches with the “regionaal distributienet” previously mentioned. The Zinc bromide flow battery also already showed its potential on the grid. The range of this type of battery showed its value in a range of 200 kW - 500 kW. This range matches with the “regionale distributienet” and the “lokale distributienet” (Crabtree et al., 2011). The last interesting type of battery is the flow battery. This battery has not showed its value so far but does show great potential. The battery works in a way which makes it easy to scale up the size of the battery (Crabtree et al., 2011). This way it can be matched with different parts of the electricity grid. Batteries in general show a great potential for the future electricity grid. Due to the different characteristics of batteries they can be matched to a great part of the current electricity grid. Batteries range from a few dozens of Kw to around 8 MW which makes them suitable for the “regionale distributienet” and the “lokale distributienet”.

Also mentioned as an energy storage method is the superconducting magnetic energy storage (SMES). SMES stores redundant energy in an electromagnetic field which is generated by a superconducting coil. There is some discussion in the range of which a SMES can store energy. Crabtree et al. (2011) mention a range between a few MW to approximately 50 MW as energy storage capacity. Ribeiro et al. (2001) mention a range between 0.1 MW and 100 MW as possible energy storage capacity. Taking into account the minimum range mentioned by Crabtree et al. (2011) the range of SMES covers the “regionale distributienet” and the “transportnet”. Taking a look at the electricity grid in the Netherlands, there can be stated that the energy storage systems can cover the whole electricity grid. Electricity can possibly be stored on every part of the grid.

Seasonal storage is another challenge for the electricity grid. Barton & Infield (2004) mentions three different types of seasonal energy storage (up to 4 months). Biomass, Hydrogen electrolysis and Large Hydro offer a storage solution for multiple months.

So far little energy storage systems have been realized throughout the world. This also implicates a downside of energy storage. Storing electricity has historically been economically unviable in any type of storage device so far (Denholm et al., 2010). The costs simply outweigh the revenues. The increasing costs of electricity however can change this and as renewables penetrate further storing electricity becomes and increasing economically viable business. It is however still uncertain which type of energy storing will become dominant.

Demand side management

The penetration of renewables in combination with the growing numbers of PEV`s have caused worries about the resilience of the electricity grid (Palensky & Dietrich, 2011). Both the supply side as the demand side threaten the stability of the grid. There are however different ways of managing the demand side of electricity of which some are more thorough than others. Palensky & Dietrich (2011) divided demand side management into three categories.

1) Energy Efficiency (EE).
2) Time of Use (TOU).
3) Demand Response (DR).

Energy efficiency concerns all measures with reduces the total output of all equipment. This measure will eventually result in a lower demand of electricity. EE measure result in immediate and permanent energy savings and are therefore of particular importance. These measures however do not contribute to managing the intermittency of renewables and the demand of the PEV thus not solving the problem of the intermittency and PEV demand.

The Time of Use concept is aimed at penalizing certain periods of time on the day by charging a higher price for electricity. These periods are the moment the electricity demand is the highest. The goal is to stimulate companies and households to shift certain electric consuming activities to another point on the day. The price schedule of TOU are on fixed in a contract and are therefore inflexible (Palensky & Dietrich, 2011). The main advantage is that household and in particular companies can structurally shift their high consuming activities to a time in which the price and the total demand is lower. TOU does not influence consumption quantity but it does influence the consumption patterns. Due to the inflexibility of TOU and the irregular generation of renewables, TOU is a measure which cannot optimize the demand side management when the penetration of renewables is high.

Demand Response is also aimed at influencing consumption patterns. The main difference with TOU is that DR uses supply and demand as a way of determining the price of electricity on the moment itself. Determining the price of electricity can be determined a few days before or it can also be determined by real life pricing. DR is a measure which can influence consumption behavior as a respond on the fluctuating output of renewables.

Forecasting is of crucial importance for DR to succeed (Moslehi & Kumar, 2010). When renewables penetrate further into the total generated electricity supply errors in the weather forecasts can have increasingly severe consequences for the stability of the electricity grid. But also forecasting demand behavior is of importance. Not knowing what the demand behavior will be in the near future means real time pricing cannot adjust to this as well.

Palensky & Dietrich (2011) divide DR in two types; Market DR and Physical DR. Market driven DR is on a voluntary base in which real time pricing, price signals and other incentives are used to match supply and demand. Physical DR is a more drastic measure in which grid management and emergency signals are the most important aspects. Market DR and Physical DR are complementary to each other. The grid operator always has to attempt to keep the grid stable with Market DR. However, when an emergency situation occurs (by for example a miscalculation in the forecasts), Physical DR is activated. Physical DR sends out binding requests to parts of the grid which deactivates or activates certain activities or can decouple certain parts of the grid to avoid a total shutdown or meltdown.

An example of activities which can be ceased are given by Palensky & Dietrich (2011). They describe a DR system in which activities of companies/ households are divided into three different categories. The activities of category 1 are of vital importance and cannot be ceased via DR. On the other side the activities in category 3 are not of vital importance and can be ceased when needed. An example of a category 3 activity is the heating of buildings. Temporarily ceasing the heating does not have a catastrophic effect in general and therefore heating should be in group 3. Examples of category 1 activities are traffic lights and a hospital. Figure 13 shows schematically how Physical DR should work. Category 3 activities are ceased almost half of the time and category 1 activities keep running no matter what.

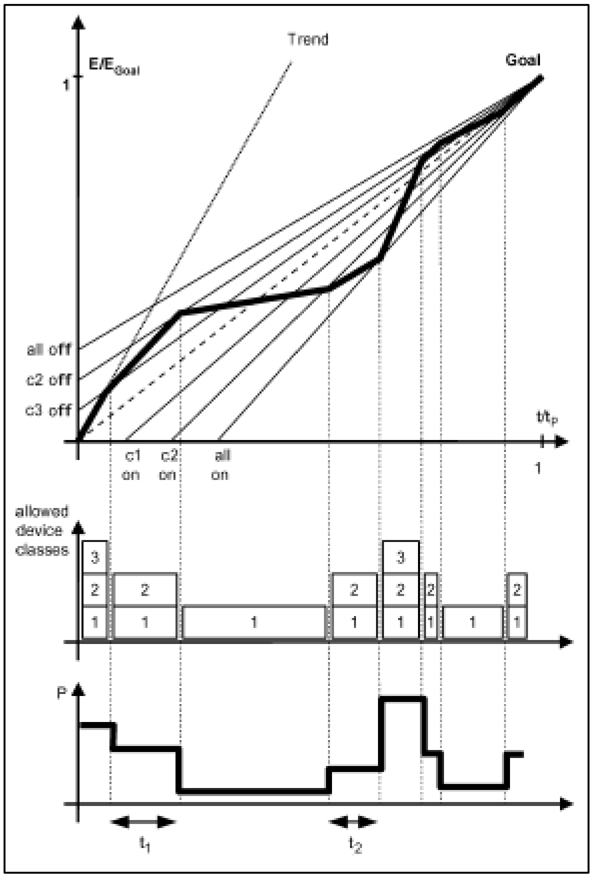


Figure 13: Visualization of Demand Response
Source: Palensky & Dietrich (2011)

2.4.4 Plug-in Electric Vehicle

Plug-in Electric vehicles (PEV`s) are a much promising development which will have influence on the performance of electricity grids. Last decades the popularity of PEV`s have grown and diminished (Masoum et al., 2010). Limitations of the PEV`s have been the large costs, limitations in battery technologies, limited driving range and a lack of adequate electrical infrastructure (Masoum et al., 2010). Since the last decade however the development of PEV`s seems to gain momentum. This was triggered by the depleting sources of fossil fuels and the increasing demand of sustainability by the society. There are positive and negative sides of PEV`s.

The positive side of this is that it will replace the fossil fuels cars and temper the greenhouse effect. On the other side the increase of PEV`s will increase the use of electricity significantly. Especially when the charging scheme of many PEV`s overlap, peak demands will occur, which stresses the electricity grid (Masoum et al., 2010). When the recharging is done on peak hour moments the peaks will increase dramatically as shown in figure 14. The concept of Smart Grid can manage this by controlling the electricity flows. However, the electricity flow can be managed the demand on the moment the PEV`s get plugged in, the total demand does not change. Managing the electricity flow will consequently give priority to certain users on the grid which will also mean some vehicles are not charged. Besides the enormous increase in electricity de by PEV`s there is also some deviation in the daily demand of electricity from the recharging of PEV`s. The daily demand for PEV`s usually differs between 1% and 7% from the forecasted electricity need (positively and negatively) (Saber & Venayagamoorthy, 2012). This unpredictability increases the chance of potential stresses and overloads.

As already argued PEV`s can cause a significant increase on the peak load moments but there is also a concept of PEV`s which can reduce the peak load moments (Kempton et al., 2005, Sortomme & El-Sharkawi, 2011, Peterson et al., 2010). This concept is referred to as Vehicle-to-grid (V2G). The concept of V2G is that a PEV is not only seen as an electricity consumer but also has a battery in which electricity can be stored. The goal of V2G is to flatten the electricity demand curve as shown in figure 15. Cars are charged on moments the demand of electricity is low and on the moments the demand of electricity is high (peak moments) PEV’s will give electricity back to the grid. A research with V2G in Amsterdam has shown that the independency of renewables increased from 34% to 65% in a two-year research project, which shows the potential of V2G (Amsterdamvehicle2grid, 2017).

Besides the increase in electricity demand the type of battery used in PEV`s is also of importance. This is also argued by Masoum et al. (2010) who divide the charging in slow, medium and fast charging of the batteries. Masoum et al. (2010) firstly conclude that PEV`s will have a significant impact on the performance of a Smart Grid. Secondly they connect the different charging times to a different part of the grid. Slow and medium charging is connected to the residential grid with the lowest capacity and the fast charging is connected to the residential grid which has the highest capacity. The charging time of slow, medium and fast charging batteries are roughly six, four and one hour. Fast charging on the lowest

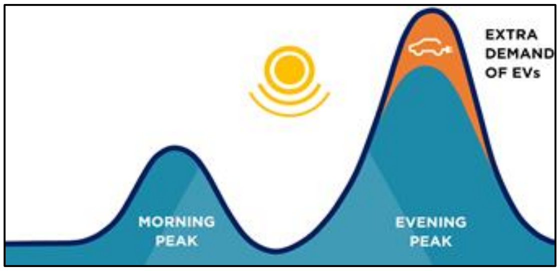


Figure 14: Peak load increase.
Source: http://www.amsterdamvehicle2grid.nl/

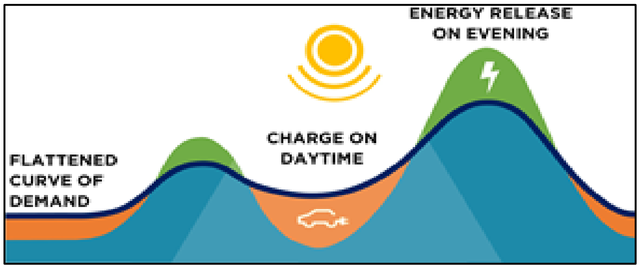


Figure 15: Vehicle to grid.
Source: http://www.amsterdamvehicle2grid.nl/

residential grid is not desirable due to the impact on the grid. The fast charging schemes can also have advantages. If a high generation of electricity occurs due to weather conditions the fast charging scheme can protect the grid from a meltdown better than a slower charging scheme. Having the possibility of different charging times can be a valuable addition to the electricity grid. However, if these charging schemes are not managed by rules and regulation it can also influence the stability of the grid.

A factor influencing the popularity is the driving range of PEV`s. Currently the driving range of PEV`s do not meet up with the demanded range of potential users (Franke & Krems, 2013). More specifically, Franke & Krems (2013) noted that the demanded range is more a psychological issue. The actual range of the PEV`s already meets up with the need of most trips but for potential users the driving range is a key uncertainty which withhold them of purchasing a PEV. Adding up to this is the possible absence of recharging poles which gives an uncertainty about the maximum range which a user can drive. These two factors negatively influence the perceived self-control of potential users and increases the stress these users might experience and eventually holding them back from purchasing a PEV (Franke & Krems, 2013).

Concluding, PEV`s will increase the use electricity significantly and this increase cannot be predicted fully (7% deviation). This can cause stresses and overloads on the electricity grid. Especially when the demand for charging PEV`s is the highest on peak moments this can stress the electricity grid. V2G is a concept which can reduce the peak moments by using the PEV`s as a battery which can charge on moments the electricity demand is low and which can give electricity back to the grid on peak demand moments. This can be managed by a Smart Grid which manages the supply and demand side. There is however, much uncertainty about the range of a PEV which demotivates potential buyers. This uncertainty consists of two important factors. Firstly, is the driving range sufficient for potential future trips and secondly, is the recharge pole infrastructure sufficient for potential trips.

2.5 Smart or Smarter Grid?

Having identified and described the most promising aspects for the future electricity grid, this chapter will critically reflect on the composed definition of a Smart Grid in section 2.2 which has been defined as:

“A Smart Grid is a modern electricity grid system which entails the whole electricity system, from generation to consumption, and uses two-way cyber communication technologies to smoothly integrate renewable energy and achieve a more clear, safe, reliable, resilient, efficient and sustainable way of managing supply and demand of electricity”.

The previous section identified the most important aspects which could be present in a future Smart Grid. Because a Smart Grid can be realized on a variety of ways there is not a single agreement of what a Smart Grid exactly is (Collier, 2010). As there are more aspects present on the grid, it grows more complex. If for example wind turbines or solar panels will have a large share in the total electricity generation much more generation units will appear on the grid. And what if the consumers become prosumers? These are just a grasp of what can happen to a future Smart Grid. And as the grid grows more complex the grid also has to become “smarter”. In fact, managing a more complex grid effectively is almost synonym to having a “Smarter Grid”. This is also stated by Palensky & Dietrich (2011) who discuss the various possibility of demand side management. The various possibilities off demand side management add “a certain portion of smart to the grid”. The aspects mentioned in the previous section are the most discussed applications in literature and these aspects determine the complexity of the grid, hence determine the “portion of smart” which has to be added to the grid to keep the grid stable. As Smarter Grid is an indication of how well an electricity grid can be managed, it is more interesting to talk about a Smarter Grid instead of a Smart Grid.

2.6 Summarizing the variables

This section will give a brief overview of the different variables used in scenarios, the characteristics of these variables and on which part of the grid they can be implemented. All this is done in table 1. Below this table is figure 15, which is also used in section 2.2 and is a visual representation of the current electricity grid in the Netherlands. In the 4th column of table 1, the different variables are colored according to the colors of the different parts of the electricity grid in figure 15, to give an overview of which aspects operate on which part of the electricity grid. The structure of the second column in table 1 will be used in the scenarios in section 4.4 which makes the scenarios easy to compare. What can be concluded is that there are many types of electricity generators and many types of balancing methods. Consequently, there are many uncertainties. For example: Which type of electricity generator will become dominant in the future? And what will the role of the PEV be in the future? The next section, the second part of the theoretical framework, will describe and discuss different approaches to give insights in uncertainties.

	Variable	**Main characteristics**	**Part of the grid**
Types of electricity generators	Conventional electricity generators (Coal and Gas)	Can be adjusted to the demand Gas generators used to supply peak load demands due to flexibility Coal generators traditionally used as base load but new generators are more flexible and can also accommodate peak load demands	Central part of the grid (koppelnet and transportnet). Depending on the capacity that can be generated. The koppelnet demands a capacity of >500MW which are usually the coal power plants and the transportnet demands a capacity between 10MW - 500 MW which are usually the gas generators
	Renewables (Solar PV and wind turbines)	Cannot adjust to the demand Solar PV: Output in the summer is higher than in the winter Solar PV: Output dependent on the sun. This can differ on various time scales	Solar PV: Decentral part of the grid. Solar panels on individual houses can be connected to the lokale distributienet and solar farms can be connected to the regionale distributienet Wind turbines:

		Wind turbines: Output in the winter is higher than in the summer Wind turbines: Output dependent on the wind. This can differ on various time scales	Both central and decentral part of the grid. Individual wind turbines can be connected to the regionale distributienet and wind turbine farms can be connected to the transportnet
Balancing methods	Energy storage	Used to manage the supply	Electricity storage can be applied on all parts of the electricity grid through different storing techniques
	DSM	DSM to manage demand with EE, TOU, DR	DSM is used in individual households which are connected to the lokale distributienet
	PEV	Electric vehicles can have a significant impact on the demand side on both the total demand and peak demand Electric vehicles can be used as an electric storing device (V2G)	PEV is applied on the lokale distributienet

Table 1: Overview of the identified aspects.

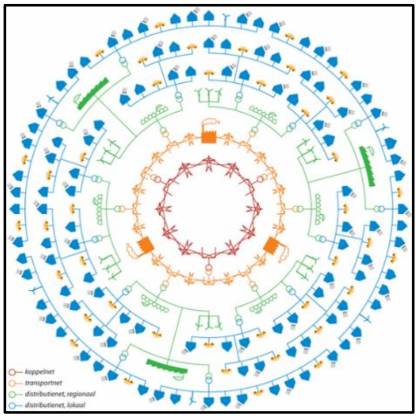


Figure 16: The electricity grid and its different parts
Source: https://phasetophase.nl/

2.7 Towards a suitable approach to tackle the uncertainties

The theoretical framework is divided in two main parts. This is the second part which is aimed at selecting a suitable approach to deal with the uncertainties surrounding the electricity grid in the Netherlands in 2035-2040. This section is divided in three parts. This first part will describe six different approaches to deal with uncertainties. Consecutively: Optimal Control, Hedging, Adaptive Management, Scenario Planning, Transition Theory and Incremental Planning are described.
The next part is dedicated to comparing and discussing on the previously described approaches. At the end of this part the most suitable approach will be selected. The approach which is ought the be the most suitable is described in more detail in the last part of this section.

2.7.1 Approaches and theories to tackle uncertainties

Throughout time different approaches have been developed to different characteristics of the system. Peterson et al. (2003) describes four different approaches of which each suits the best to a particular situation. These approaches are Optimal Control, Hedging, Adaptive Management and Scenario Planning. To determine which approach is the most suited in a particular situation Peterson et al. (2003) identified two important characteristics of the system. Firstly, the degree of controllability and secondly the degree of uncertainty as shown in figure 16**.** Baron et al. (2009) elaborate on this figure and state that the amount of certainty or uncertainty relates to the complexity of the system. A more complex system automatically means that uncertainty increases. If Optimal Control or Hedging is applied in a situation with much uncertainty the results can be different than expected due to the complexity of the system. Due to the complexity of the system certain actions may influence aspects which were not expected and results may be opposite of what was expect. An example of this is pointed out by Stanford & Ellis (2002). To increase the salmon population of different lakes in the United State a fresh water shrimp was introduced which should be a source of food for the salmon. The shrimp however consumed a large amount of zooplankton in the lakes, a source of food for many different types of fish. The population of many fish species declined and on top of that the behavior of the fresh water shrimp did not suit the salmon. Instead of an increase of the salmon population the whole fish population of the lakes dropped. Controllability is highly related to the amount of influence an institution has on a system and the influence on the system itself as a whole (Baron et al., 2009). If only one institution is involved in the control of the system, the institution has a high amount of influence over the system as a whole. If the amount of institutions controlling the system increases, every individual institution needs to share their influence with other institutions hence decreasing the overall influence of an institution over the system as a whole. Besides the amount of institutions also technological developments can greatly influence systems. An example of this is the introduction of the internet which has changed society on many aspects.

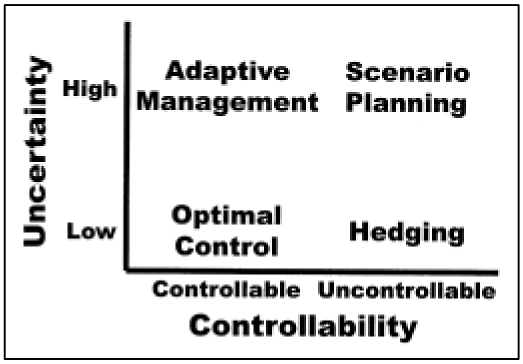


Figure 16: Four approaches to tackle uncertainties Source: Peterson et al. (2003)

As the main research question suggests, the energy transition demands a change of the electricity grid in the Netherlands. Therefore, transition theory and transition management are other possible approaches to take into consideration. Meadowcroft (2009) defines transition management as:

“At the core of ‘transition management’ is the challenge of orienting long-term change in large socio-technical systems. ‘Transitions’ are understood as processes of structural change in major societal subsystems. They involve a shift in the dominant ‘rules of the game’, a transformation of established technologies and societal practices, movement from one dynamic equilibrium to another—typically stretching over several generations (25– 50 years)”.

The management part refers to the deliberately guiding the transition to the desired pathway (Meadowcroft, 2009). Kemp (2010) adds to this that a transition is rooted in a multidisciplinary approach. This also means that different professions are involved in a transition like; Scientists, historians, politicians. Kemp (2010) categorizes transition thinking into four categories; socio-technical transitions, transition management, social practices and system thinking, and reflexive modernization.

There seems much similarities between the subject of the thesis and transition theory. For example, the governmental goal of the Netherlands to be climate neutral in 2050, which is the instigator of the change on the electricity grid in the Netherlands. The time span a transition usually needs concerning Meadowcroft (2009) suits the goal of being energy neutral in 2050. Also the structural change which is needed in societal subsystems and the transformation of established technologies are present in the energy transition. Gas and coal fired power plants need to be replaced by renewables and society is also involved due to for example the high resistance of wind turbines on land. Transition theory is often seen as a type of governance model (Kemp & Rotmans, 2005). Three levels of the system are identified by (Loorbach, 2007). These are the macro, meso and micro level (figure 17). The macro level concerns social values, political cultures, build environment and economic development. The meso level concerns dominant culture, structure and practice embodied by physical and immaterial infrastructures and the micro level concerns new technologies, new rules and legislation, new organizations or even new projects, concepts or ideas. Transition theory concerns the governance of these three levels to eventually provoke a transition towards a new system, in this particular case a transition towards a sustainable electricity grid.

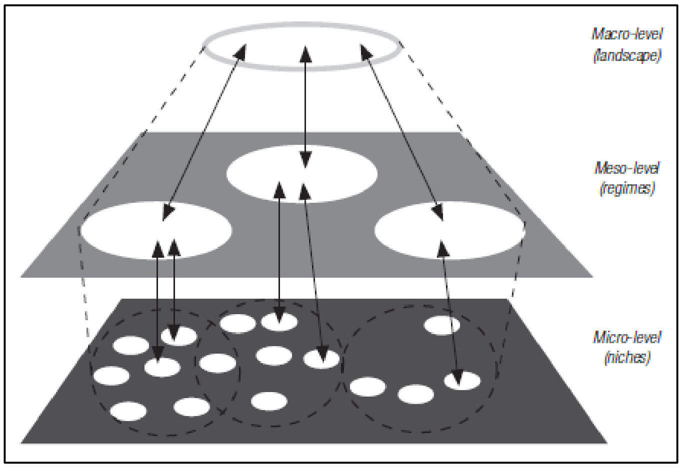


Figure 17: Macro, meso and micro level of transition theory
Source: Loorbach (2007)

The last theory to be discussed is incremental planning, called “The science of muddling through” by Charles Lindblom (Hudson et al, 1979). The advocacy of incremental planning derived from critiques on the synoptic reality (Hudson et al, 1979). The critiques where aimed at several characteristics of the synoptic planning approach. Firstly, the critiques were aimed at the highly centralized planning approach. The highly centralized decision-making where often not understood or accepted by the local population (Hudson et al, 1979). A shift towards a more decentralized planning approach, where local governments take responsivity would decrease the resistance of planning, is advocated by incremental planning. Other critique on synoptic reality was that it did not question the institutional capabilities, its reductionist epistemology and the failure to recognize the cognitive limits of decision-makers (Hudson et al, 1979). The complexity of reality was reduced to make it understandable for decision-makers. By reducing the complexity of reality decision-makers were able to develop long term blueprint plans.

Concerning incremental planners, the planning should be done on a decentral level, where long term goals are loosely formulated, leaving room for change, and where stakeholder consultancy is of vital

importance. To reach to the long term formulated goal, smaller short term, more concrete plans should be developed with active stakeholder consultancy (Tillner, 2013). The shift from a technical rational reality, which reduces the complexity to understandable pieces, to an agreed reality were stakeholder consultancy tackles the complexity of planning and the possible resistance of the (local) population.
Concluding, incremental planning can be described as a decentral planning approach, where stakeholder consultancy is of vital importance to tackle the complexity of the problem. Long term goals are formulated more general and are attempted to be reached by short term concrete plans on which consensus is reached by active stakeholder consultancy.

2.7.2 Why scenario planning?

Uncertainty and controllability
To determine which approach of the above six approaches is the most suited, the electricity system in the Netherlands in 2035-2040 will be analyzed, determining the uncertainty and controllability. Uncertainty is closely related to the complexity of the system (Baron et al., 2009). The energy transition is a complex phenomenon on itself. This is also reflected in the electricity grid where the transition from a conventional electricity system has to be replaced by a sustainable electricity system. But as mentioned in the previous sections, to empower this transition simply replacing conventional generators for renewables will cause intermittency problems. As for example table 1 shows, different balancing techniques are available but not one type of balancing method is dominant. Many different solutions and arrangements are possible depending on future developments. Altogether the uncertainties of the future electricity grid in the Netherlands are high.
The controllability is dependent on the amount of institutions which can influence the electricity system in the Netherlands in 2035-2040. Due to the presence of many electricity generating companies the influence of every single institution is diminished and shared. Also the grid administrators, both nationally and regionally are institutions which can operate freely to a certain extend. However, the grid operators are also influenced by the national government, who can determine the paths of the grid operators to a certain extend. The above mentioned institutions are just a grasp of the variety of institutions involved in the development of future electricity grid in the Netherlands. The institutions mentioned are all active within the electricity system in the Netherlands but also institutions from outside the system can influence the electricity grid in the Netherlands. For example, the European Union which had a share in the energy transition by determining which goals every single country had to achieve. All these institutions are influenced by society as a whole. Altogether the controllability is low and the uncertainty is high of the electricity grid in the Netherlands in 2035-2040, which makes scenario planning the most suited approach of the four approaches in figure 16.
However also two other approaches are developed to tackle complex, uncertain, hard to control phenomena. Transition management is by definition an approach which deals with a complex phenomenon, a transition. This has been argued by defining transition management in the previous chapter.
Incremental planning has been developed as a reaction on the failure of synoptic planning approaches. It was argued that synoptic planning approaches could not tackle the complexity of certain phenomena with a technical rational approach. Instead it was advocated that a more communicative rational approach should be used to tackle the complexity.

“At the core of ‘transition management’ is the challenge of orienting long-term change in large socio-technical systems. ‘Transitions’ are understood as processes of structural change in major societal

subsystems. They involve a shift in the dominant ‘rules of the game’, a transformation of established technologies and societal practices, movement from one dynamic equilibrium to another—typically stretching over several generations (25– 50 years)”.
Moreover, the electricity grid in the Netherlands, and the demanded change of the energy transition have much in common with transition theory. Transition theory can be applied best at highly complex systems in which many stakeholders are active.

A striking difference between transition theory and scenario planning is the specific outcome of both approaches. Transition theory describes the arrangements of institutions within the three different levels (macro, meso, micro). The different institutions are arranged in a way social-technical developments are optimally stimulated. Governance of these different institutions is the key element in transition theory. Arrangement of the system is also influenced by the governance of the different institutions but this is only implicitly. Scenario planning on the other hand often has the consequences explicitly described in the different scenarios. The set of scenarios all describe a different future with a different arrangement. Whereas the spatial consequences are often explicitly in scenario planning, the arrangements of institutions are implicitly present. If for example a scenario tends towards a certain direction it can be argued that institutions active in that particular direction are more present in that specific scenario.
Taking this in consideration another look to the main research question is needed which is:

“How can scenario planning offer insight in the uncertainties which go hand in hand with the energy transition and the spatial implication for the electricity grid in the future in the Netherlands?”

The goal of this thesis is to offer insights in the uncertainties of the energy transition and the implication for the electricity grid. The implications are a key element in offering insights in the uncertainties which means the implications have to present explicitly. Institutional arrangement is implicitly present in these spatial arrangements but are a consequence of the spatial arrangement.
Incremental planning also focusses on institutional arrangement. More specifically it advocates a decentral institutional arrangement where stakeholders are consulted actively. Short term, more concrete plans are developed with the stakeholders. A series of concrete short term plans can be able to reach to long term formulated goal. In the specific subject of this thesis would mean that together these short term plans can reach the goal of the energy transition (a CO_2 neutral society). However, every short term plan is individually shaped with stakeholder consultancy which makes it hard to predict what the implications of these plans together are for the electricity grid in the Netherlands in 2035-2040.
Because both transition management and incremental plan lack the capability of effectively describing precise implications for the electricity grid in the Netherlands in 2035-2040 they are not the most suited approach for this thesis. The only approach which is discussed and explicitly describes implications for the future electricity grid is Scenario Planning. Hence scenario planning will be used as the approach to offer insights in the uncertainties which surrounds the electricity grid in the Netherlands in 2035-2040. The next section will elaborate on scenario planning.

2.7.3 Key theory of scenario planning

Practical use of scenario planning first started to appear in the 1970s at the oil company Shell (Peterson et al., 2003). The value of scenario planning for Shell became clear at the oil crisis in the 1970s and in the 1980s in which Shell also described a scenario in which oil price declined due to other non-OPEC discoveries (Peterson et al., 2003). By using scenario planning Shell was better prepared than their competitors and therefore Shell was able to react better on the changing circumstances and outperformed their competitors (van der Heijden, 2011). Scenario planning has proven its value already and more organizations adopted scenario planning as a way to deal with the future.

However, through time many theories of scenario development have emerged which made this a particular fuzzy research field (Börjeson et al., 2006). Stremke et al. (2012) describe a “cyclic scenario approach” based on the approach of Dammers et al. (2005) which uses a four step approach for scenario design as shown in figure 18. This figure shows there is no clear ends and this is emphasized by Dammers et al. (2005) who argue that this process has to been run through several times. Especially step 2 and step 3 are interesting since it shows different types of scenarios exist and these scenarios are closely interlinked with each other in a cyclic approach. These two types of scenario also have a different nature. The external scenario focuses on trends outside the organization and thus can only be influenced in a limited way. Typical variables in explorative scenarios are developments on the technological, economic and societal part of society. This type of scenario design has an explorative function for an organization. Sketching different external scenarios is the point of departure for the policy scenarios. Policy scenario have a normative function which means it has a prescribing function (Stremke et al., 2012). Knowing how the world outside can develop opens up the possibility for politicians and planners to steer these developments towards a favorable outcome, which is exactly the goal of policy scenarios. This might sometimes mean planners and politicians do not have to do anything but can also mean different rules and regulations have to be introduced to guide the developments. Another notable aspect of figure 18 is the process which goes from the present concrete (step 1) to an abstracted future (step 2 and 3) back to the present cornet again (step 4). Van Kann (2015) reflects on the cyclic scenario approach and states that the process is a time consuming matter. Furthermore, constructing external scenarios demands a significant amount of resources and especially expertise (Van Kann, 2015). The process of the cyclic scenario approach can also be simplified by using existing external scenarios. Using existing scenarios saves time and this gives to possibility to focus more on the policy scenarios when these are the main point of focus of the research.

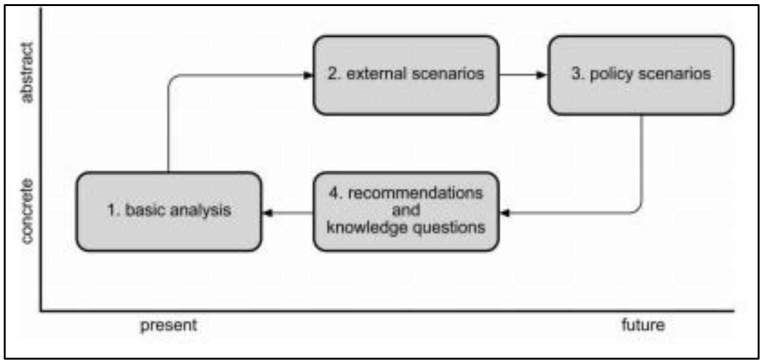


Figure 18: Cycling scenario approach *Source: Stremke et al. (2012)*

The normative and explorative type of scenario also appears in Börjeson et al. (2006). In their publication they analyze different categorizations of scenarios by different authors and conclude that all these different categorizations can be placed underneath three questions: These are *What will happen? What can happen?* and *How can a specific target be reached? (Börjeson et al. 2006, pp. 725).* In the same order of these questions three types of scenarios can be identified: predictive, explorative and normative scenarios as shown in figure 19. The scenarios are further categorized because the types of scenario can have a different angle of approach. Börjeson et al. (2006) state that the *forecast scenario* is aimed at trying to identify what will happen if the most likely development unfolds. The scenario consists of an average with a high

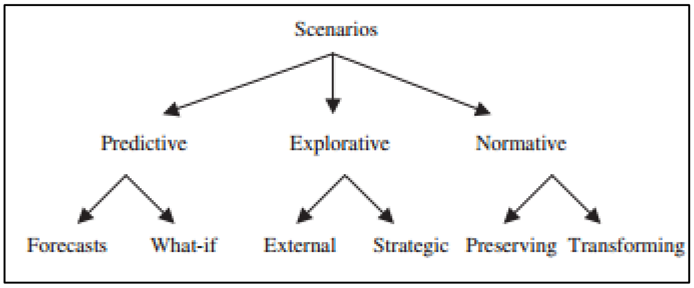


Figure 19: Types of scenario *Source: Börjeson et al. (2006)*

and low span as extremes. *Forecasts* are usually aimed on internal variables and are most suitable for short term predictions. An example of this is the weather forecast of the next week and the minimum, maximum and average development of the temperature. The *what-if scenario* is aimed at what will happen if a certain event occurs. This can also mean that it is a chained path of several what if`s are connected to each other. The answer on what-if is usually yes or no. The variables are usually external but can also be internal and are also aimed on a short term. Due to the short time-frame the predictive scenario types usually do not contain a total system change.

The *external and strategic scenarios* are aimed at constructing several possible futures. Both scenarios usually cover a longer time-frame, thus integrate a possible system change in their story. The difference between the *external* and *strategic* types is that the external scenario, as the name suggests, focuses on the possible changes of external variables whereas the strategic scenario focuses on the internal variables. This does not mean that strategic scenarios do not take into account external variables. An external scenario is often used as input for a strategic scenario. Strategic scenarios focus on possible policies of an organization when a certain external event occurs. This makes strategic scenarios a possible extension of an external scenario.

The normative scenario types prescribe how a specific target can be reached. The difference between the *preserving* and *transforming scenario* is that a preserving scenario is aimed at reaching the goal within the same system structure. The goal of the preserving scenario is to describe how a specific target can be reached as efficient as possible. The transforming scenario suggests that a target is hard or impossible to reach unless a system change occurs. The goal of the transforming scenarios is to encourage finding different paths on how a goal can be reached, which is called back casting (Höjer & Mattsson, 2000). Putting this in the light of Stremke et al. (2012) this means you first describe the basic analysis (step 1) and then describe the policy scenarios (step 3). This differs from the other scenario typologies as they are forecasting types of scenarios. The preserving scenario is aimed on a longer time frame and the transforming scenario is aimed at a very long time frame (25- 50 years). The preserving scenario takes into consideration the internal and external variables whereas the transformation does not have to make the bifurcation between internal and external variables. Höjer (2000) states that without this bifurcation all options are kept open and no restrictions are imposed.

Peterson et al. (2003) state that it is important in scenario building to separate internal and external forces from each other. This differs from the transforming scenario type of Börjeson et al. (2006) as they state that in this type of scenario no bifurcation has to be made between internal and external forces. The external forces are considered as important forces influencing the design of all the scenarios and are considered the same in all scenarios. The different scenarios should all meet the demands of the external forces. The internal forces are used to meet the demands of the external forces. The specific combination of the internal forces describe how the scenario exactly looks like. Within the storylines of the scenarios the internal assumptions and the differences in the storylines must be clearly visible, otherwise the scenarios could have too much in common with each other (Peterson et al., 2003). Comparing the typology of Börjeson et al. (2006) and Stremke et al. (2012) a complementation becomes visible. The typologies of Börjeson et al. (2006) appear on different parts of the process described by Stremke et al. (2012) as shown in figure 20. The explorative external scenario type is used in step 2 of Stremke et al. (2012) cyclical scenario approach. This type of scenarios is used as input for the next step in Stremke et al. (2012) which is the development

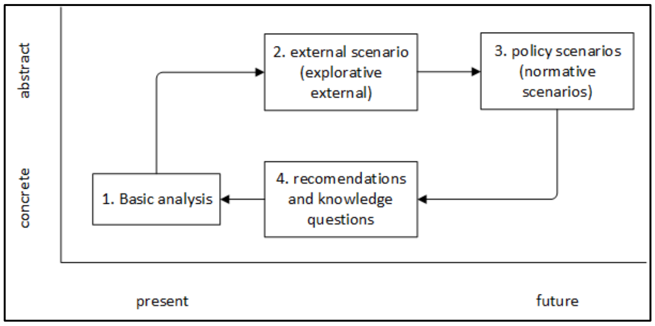


Figure 20: Merging the tyoplogy of Börjeson et al. (2006 and the cyclical approach of Stremke et al. (2012)

of policy scenarios. Stremke et al. (2012) state that the policy scenarios have a normative approach which coincides with the two types of normative scenarios of Börjeson et al. (2006).

To make sure the scenarios are a possible option in the future they have to be anchored in the past (Peterson et al., 2003). This is done in the step 1 which describes the current state of the system. However, another approach is also a possibility. Börjeson et al. (2006) state that a method for developing normative scenario is back casting. This method first describes the basic analysis (step 1), then describes a (normative) goal and several possible futures how this can be reached (step 3). This approach of scenario developing is also described by Dammers et al., (2013). Dammers et al., (2013) describe that the external forces are combined with the policy scenarios in a way that the external forces give an explanation for the specific scenario. The main question is; *What external forces could have caused the development towards that specific scenario?* Dammers et al., (2013) refers to this as the "drijvende krachten" which can be translated as *drivers.* Step 4 in the process of generating scenarios are recommendations and knowledge questions. Dammers et al., (2013) divide this step into "points of attention" and "recommendations". The points of attention focusses on the consequences of the external scenarios whereas the points of attention focusses on the consequences of the policy scenarios. In case of back casting policy scenarios, the points of attention are of less importance since the development of the external forces are subjected to the policy scenarios. The focus in this type of scenario development should be on the consequences of the policy scenarios which is step 4 in the process.

As figure 20 shows the consequences have to be more concrete than step 3. This is because step 4 focusses on what things of the system has to change in order to achieve the scenario described in step 3. Therefore, the consequences of every scenario for the system should be clarified in this step. After this the different scenarios can be compared, focusing on what aspects the scenarios have in common and what aspects are scenario specific. Another approach of organizing the comparison is described by Stremke et al. (2012) who divides the outcome of the comparison in short and long term actions. The short term action should be applicable in all scenarios whereas the long term action can be applicable between one and all scenarios. Actions which are applicable in all scenarios can become part of a master plan (Carsjens, 2009). Actions which are not applicable in all scenarios can become part of contingency plans (Maack, 2001). The variables influencing the different scenarios and describing the current system should be a central aspect in this step. This way the development of these different variables becomes clear in the scenarios. The last step is aimed at describing short term and long term action the support the policy development (Stremke et al., 2012). The short term action ought the to be applicable in all scenarios whereas the long term action can be applicable between one or all scenarios. Long term action which appear in all scenarios can become part of a master plan whereas long time action not applicable in al scenarios are scenario specific and part of a contingency plan (Carsjens, 2009).

Lastly it should be noted that scenarios in general can be used in different ways. For example, the forecasting method uses scenarios to give an accurate prediction of the future. The scenario itself is an accurate prediction of the future. If scenarios are used to seek a masterplan and contingency plans, the scenario itself are not used to give an accurate prediction of the future. Instead they are used as an approach to offer insights in uncertainties by comparing them. The scenarios cover a range of the possible direction a system can develop to.

2.8 Conceptual Model

No matter under what conditions the electricity grid operates the ultimate aim is to keep the grid reliable at all costs. The different variables previously described are the key elements to keep the grid reliable. Currently conventional energy sources are the main suppliers of electricity on most grids. Conventional energy sources are easily managed which makes them an energy source that makes the grid reliable. However due to environmental issues renewables are needed. This will have an impact on the reliability of the electricity grid.

Keeping the grid reliable means it has to stay within the boundaries of 48.8 Hz - 50.2 Hz. When there is a tendency of an overload over electricity on the grid the electricity will tend to go to 50.2 Hz. Going above this can mean a meltdown of an electricity cable can occur and a blackout of a part of the electricity grid. Going below the 48.8 Hz will mean electricity is relatively scarce which can also cause a blackout of the electricity grid.

Eventually, for all scenarios the grid has to stay balanced. The supply side has to match the demand side or vice versa. This brings us to the model shown in figure 21. One side of the scale resembles the supply side (left) and the other side resembles the demand side. An unbalanced supply and demand side will mean the grid goes out of the 48.8 Hz - 50.2 Hz border. This is shown in figure 22 which shows a surplus in the supply side and figure 23 which shows a surplus in the demand side. In the different scenarios the balance will be managed in different ways but always have to stay in balance as figure 21 resembles.

Figure 21 will be integrated into the conceptual model which will be used in the scenarios. The conceptual model for this thesis is shown in figure 24 (page 39).

This model is a combination of the generic way of developing scenarios and the specific input of the possible developments on the future electricity grid in the Netherlands.

The first step, the basic analysis is aimed at describing the current situation. In this step the current situation of variables, used in the scale, are analyzed and described. Also the general characteristics of the current situation are described in this step. Eventually this step should give an overview of the current situation aimed at the specific situation of the Netherlands.

The second step is aimed at describing the context of change. Because several scenarios will be described the context of change is different for every situation. The context of change can be described in several ways. It is not uncommon to use already existing scenario's as input to spare time. Also the full process of creating external scenarios first, on which the policy scenarios are based is a possibility. In this thesis a different approach will be used. The goal is set up a set

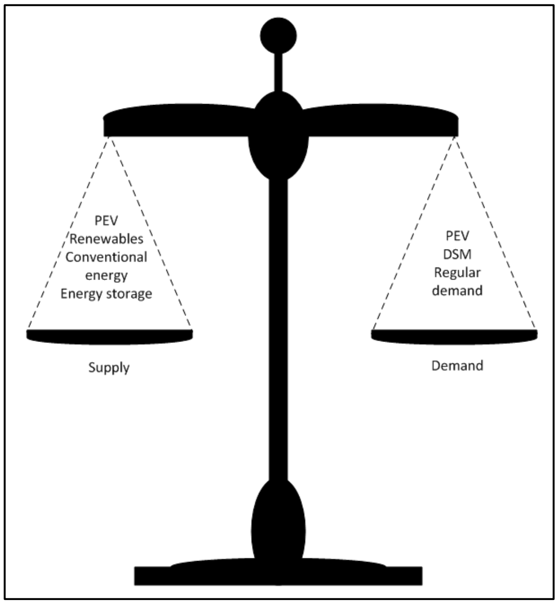


Figure 21: A balanced electricity grid

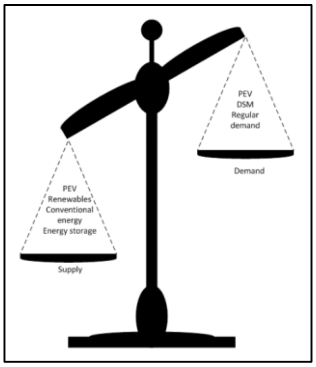


Figure 22: Unbalance of supply and demand

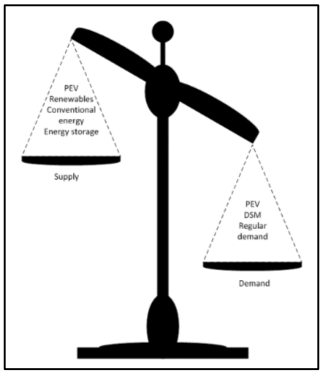


Figure 23: Unbalance of supply and demand

of policy scenarios which cover a range in which the electricity grid in the Netherlands in 2035-2040 can develop to, taking into consideration the energy transition. These policy scenarios all have different contexts of change. The contexts of change are however not used as input to develop the policy scenarios but this process is reversed. The context of change is submissive to the policy scenario's. The main question in this part of the development of the scenarios is; What developments have taken place in the Dutch energy system which could have caused the system to go towards the direction of the specific scenario. This means that this thesis will use the back casting method as a way of developing the scenarios. The third step is developing the policy scenarios. The scale described in figure 21 is used as point of departure for the development of the policy scenarios. The variables present in the scale will be different in every scenario, due to the different developments in every scenario but will all be addressed. The developments of the different variables in the scale will also influence the environment.

The fourth, and last step is a comparison of all the scenario's. What do the scenarios have in common, what does not appear in all scenario's and what does not appear in any scenario? Aspects which appear in every scenario will be part of a masterplan and aspects which appear in only in two or three scenarios will be part of a contingency plan. Developments which appear in only one scenario will not be part of a contingency plan. This part will also be used to answer the main question of this research. Aspects of a masterplan are robust intervention for the future electricity grid of the Netherlands, aspects of a contingency plan are depended on the direction the electricity system develops to and aspects which do not appear in any scenario also offer insights of the electricity grid in the Netherlands in 2035-2040

Using the scenarios to develop a masterplan and contingency plans means the scenarios in this thesis are used as an approach, not as a goal.

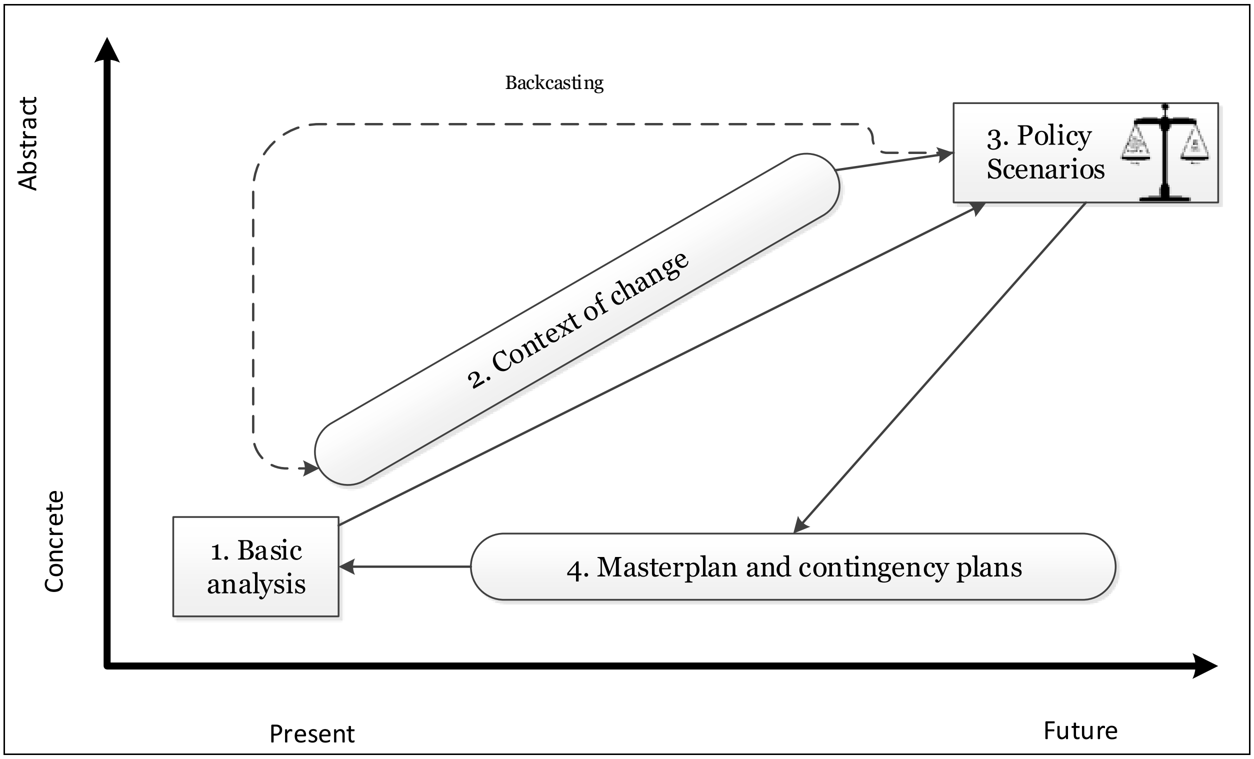


Figure 24: Conceptual model

3. Methodology

In the theoretical framework different promising aspects have been discussed which can be part of the future electricity grid of the Netherlands. These different aspects will be used to describe a set of scenarios which are extremes of the possible future. To answer the main research question, the developed scenarios will be analyzed and compared. This process is described in the conceptual model **(**figure 24**)** which is used as point of departure to structure the results. This chapter elaborates on how the conceptual model can be translated into research strategy to eventually gain insights in the uncertainties of the electricity grid in the Netherlands in 2035-2040.

Chapter 3.1 elaborates on the research strategy and what type of methodology will be used for which part of the results based on the conceptual model. Chapter 3.2. will discuss in debt why the types of methodology are used to gather data, why exactly these types of methodology are used and how they strengthen each other. Chapter 3.3 is devoted to creating an empty scenario framework and how the master plan and contingency plans can be identified in these scenarios. The empty scenario framework is used as point of departure to effectively collect data for the different scenarios.

3.1 Research strategy

The research strategy describes which steps are taken to eventually answer the main research question. Table 2 summarizes the steps which are taken.

The first step results in an empty scenario framework. This framework will be used as point of departure for the follow steps. Several options will be considered of which the most suitable will be used. The second step is the data collection and is the empirical part of the research strategy. The two different research methods have been used to gather qualitative data. Firstly, a desk research has been executed and secondly interviews with specialists have been done. Chapter 3.2 will elaborate on why these two research methods have been selected and how these research methods combined optimize the quality of the data. The third step is analyzing the collected data. Data of both the interviews and desk research will be analyzed by using a coding scheme. This coding scheme is based on the different variables discussed in the theoretical framework and the empty scenario framework developed in step 1. The goal is to match the collected data to the different scenarios. The data collected for the basic analysis and external forces are solely based on desk research. The fourth step is to analyze the developed scenarios and find similarities between the scenarios which result in a masterplan and contingency plans. These plans will offer insights in the uncertainties which surrounds the future electricity grid in the Netherlands.

Step 5 is drawing conclusions by answer the main and sub research question and the final step will discuss the results, reflect on the process of the thesis as a whole and give recommendations for further research.

Steps	**What**	**Analytical strategy**	**Chapter**
1	Creating a scenario framework	1. Analyzing the possibilities for developing a scenario framework	3
2	Data collection 1. Desk research 2. Semi structured interviews	1. Collecting policy documents, annual reports and documents about certain aspects of the grid. 2. Interviewing persons involved in the development of the grid	3

3	Analyzing the data 1. Describing the basic analysis and external forces based on desk research 2. Developing the scenarios and context of change based on desk research 3. Developing the scenarios and context of change based on interviews	1. Analyzing policy documents and annual reports by coding relevant passages. 2. Analyzing policy documents, annual reports and document about specific aspects of the grid by coding based on the theoretical framework and conceptual model. 3. Analyzing interviews by transcribing and coding the interviews based on the theoretical framework and conceptual model	4 4 4
4	Analyzing and comparing the scenarios 1. Developing a masterplan 2. Developing contingency plans	1. Analyzing the scenarios and determine what will be part of the masterplan 3. Analyzing the scenarios and determine what will be part of contingency plans	5
5	Drawing conclusions	1. Answering the main and sub research questions based on the theoretical framework, methodology and the results	6
6	Discussion and reflection	1. Discussing the final results which answer the research questions 2. Reflecting on the theoretical framework, conceptual model, methodology and results 3. Give recommendations for further research.	6,7

Table 2: Research strategy

3.2 Research methods

Data will be collected through two different types of methodologies. Firstly, secondary data will be collected by doing desk research. After this interviews will be held with persons involved in the development of the electricity grid in the Netherlands to generate primary data. In the two sections below a detailed description will be given why these types of data collection are used and what the goal is of each type of methodology. Both research methods are qualitative.

3.2.1 Desk research

Desk research is a research methodology which uses secondary data as an input source to gather information about the subject (O'Leary, 2017). This means existing texts are used as a data source for another research. O'Leary (2017) states that almost everything what we as a mankind do and document can be used as input for a desk research. Videos, blogs, logs, journals, poetry and photographs are just a grasp of possible sources for a desk research. The big advantage of secondary data sources is that the relation between researcher and the researched is minimized (O’Leary, 2017). The data collected by desk research is not influenced by the researcher through interaction with interviewed persons or by own formulated questions in surveys. This might give another paradigm on the researched subject worth considering. The disadvantage of desk research can be that the collected data is not custom build for the researched subject and that the observed documents are also biased. This bias can be for example through the test of time or by the biased researcher of the analyzed documents itself.

When the document is considered relevant the analysis of the documents can start. O'Leary (2017) states that there are two techniques of analyzing a document to extract the information needed. Firstly, this can be done by considering the documents as a respondent of an interview. Before you start analyzing the document you first have to determine what you want to know. This can be formulated in an interview guide. When the relevant questions are formulated a systematic analysis of documents can take place. With a color scheme relevant passages in a document can be highlighted. Gathering answers in the different documents will give a holistic view of the subject, hence analyzing more documents makes the collected data more reliable. Secondly a document can be analyzed by the so called “noting occurrences”. This method focusses on the quantification of specific phrases and concepts in the document. The researcher determines on which phrases and concepts the search is conducted. In this thesis the selected documents will be analyzed by considering the different documents as interviews. A coding scheme will be developed which is based on the theoretical framework. The goal is to identify specific developments and connect these developments to the different scenarios. This coding scheme will also be used for the next research method to make sure the collected data of both research methods can be compared and smoothly integrated in the scenarios.

Several documents have been analyzed and a full overview of these documents is separately mentioned in appendix 6. Together with the interviews they form the backbone of the collected data.

3.2.2 Semi-structured interviews

The second research method which is used is semi-structured interviews which also is a qualitative research method. At semi-structured interviews it is more important to retrieve qualitative in depth information, than the number of participants which are more important for quantitative research methods (Hennink et al., 2011). Interviews generate primary data which is tailor-made for the specific research subject. This makes it easy to smoothly integrate the collected data in researched subject. The disadvantage of interview data is that there is always a certain degree of bias of the interviewer is incorporated in the interview (O'Leary, 2017).

During this thesis two interviews have been executed. One interview was with Gert van der Lee, an employee at the Dutch national grid operator TenneT. This interview was executed at the headquarter of TenneT located in Arnhem because Gert van der Lee is employed at this place. TenneT is responsible for the central part of the electricity grid in the Netherlands and the goal of this interview was to collect data about future possibilities and potential developments on the central part of the electricity grid in the Netherlands. The interview was executed on Monday the 16th of October 2017.

The other interview was with Henk Schimmel an employee at the regional grid operator Enexis. This interview was executed in Groningen at the main building of the municipality of Groningen because Henk Schimmel already had an appointed here, which made this the most convenient place for both. Enexis is a regional grid operator in the Netherlands and is responsible for a part of the regional electricity grid in the Netherlands. The goal of this interview was to gain insights in future possibilities and potential developments on the decentral part of the electricity grid in the Netherlands. The interview was executed on Tuesday the 28th of November 2017.

The goal of the two interviews combined was to gain insights in the similarities and differences between a centrally organized electricity grid and a decentral organized electricity grid. The part of the grid where the national grid operator is responsible for is considered as the central part of the electricity grid (Koppelnet and Transportnet) and the part where the regional grid operators are responsible for is considered as the decentral part of the electricity grid (regionale distributienet and lokale distributienet).

Before the interviews were executed interview guides were developed. These interview guides (appendix 1 and 2) are used for the interviews and is based on the variables in the conceptual model. The interviewees where asked how/if they expected the different variables would be present on the part of the grid the grid operator was active. This approach made it possible to connect different types of generation methods, balancing methods and the PEV to different parts of the grids. Off all the developments which where pointed out by the interviewees it was also asked what the effect would be on the spatial environment and what this would mean for the electricity grid.

Interview questions were asked as neutral as possible to give the interviewees the least restrictions on their answers and to minimize the influence of the possible bias of the interviewer. This can be clarified by for example gathering data about generation methods. The personal expectation was that wind energy would be more present on the central part of the grid but to make sure this bias did not influence the interviewee the follow question was asked: “What type of renewable is expected to be the most present on the central part of the grid” instead of asking “what will be the influence of wind energy on the future central electricity grid”. Secondary questions where mainly focused on the spatial implications of the mentioned developments or what this would mean for the electricity grid.

The combination of both interviews has clearly pointed out the difference between a central or decentral oriented electricity grid. The relative importance of future developments on both parts of the grid also made it possible to make distinctions between the scenarios with the different penetration level of renewables. What was specifically noticed during the interviews was that interviews also give data of “work in progress” whereas the desk research mainly gives data of work which has been finished. This gave some new “state of the art” insights of the future developments of the electricity grid which could not have been identified with desk research only.

The interviews have been recorded, transcribed, coded and analyzed to systematically collect data. For the interviews two interview guides have been developed which are shown in appendix 1 and 2 and are based on the conceptual model. After the interviews were executed and recorded they were transcribed. The transcribed interviews have been analyzed with a coding scheme, which can be found in appendix 3.

The coding scheme was also based on the conceptual model to extract data which is tailor made for the scenarios. Lastly the coding scheme was applied on the transcribed interviews shown in appendix 4 and 5.

3.2.3 The synergy of desk research and semi structured interviews

The combination of desk research and interviews have contributed to the quality of the data. The specific characteristics and the strengths and weaknesses of the research methods strengthen each other. Desk research uses secondary input as data which makes it not especially suited for the researched subject. This makes it sometimes hard to filter relevant data from less relevant but related data. This is not the case with primary data which is tailor-made for the specific subject. By combining both research methods the most relevant data can be selected for the scenarios increase the plausibility of the scenario as a whole. On the other hand, primary data from an interview can be biased by the question asked of the interviewer. This bias can give a deformed image of the reality. Secondary data is not generated by the researcher itself but is already present data generated by other researchers. Hence the bias of the researcher is not incorporated in this data. Combining the research methods desk research and semi-structured interviews, maximizes the relevance of the collected data and minimizes the bias which can be present at the researcher.

3.3 Scenarios, masterplans and contingency plans

3.3.1 Developing a scenario framework

This section focuses on the design process of the scenarios. In this process a few options have been considered as point of departure for shaping the scenarios. The first option was making combinations of different coherent variables and how what this would mean for the spatial environment. The second option was focusing on the development of different parts of the grid which puts the grid as a central part of the design of the scenarios. Analyzing the first option pointed out that around 16 scenarios where a possibility. This amount of scenarios was found to much and the comparison between 16 scenarios is an almost impossible task. Besides this, formulating the spatial implications for 16 scenarios is a time consuming task which is not suited for a master thesis. In general, comparing 16 different scenarios to sketch possible futures is an amount which is not suitable at all for comparison (Peterson et al., 2003). Another possibility was picking a few of these 16 scenarios. In this way these scenarios were possible to use for comparison but the disadvantage was that it did not cover the whole range of possibilities. Analyzing the second option, using the grid as a point of departure, opened up other possibilities. Besides this it puts the electricity grid as a central part of the scenarios, which coincides with the subject of this thesis. Roughly the grid can be divided into two parts. A decentralized part on which all the households and most industries are directly connected and a centralized part on which all the conventional electricity generators and wind turbines parks are connected (as shown in section 2.3). Using these two extremes, a focus on decentral and central, covers the whole range of the grid. The decentral scenarios focus on developments on the “lokale distributienet” and the “regionale distributienet” whereas the centrally oriented scenario focusses on developments on the “transportnet” and the “koppelnet”. This means the partition between the central and decentral scenarios is between the “regionale distributienet” and the “transportnet”.

Only focusing on the development of the central or the decentral part of the grid still does not give enough reference points to sketch the scenarios. Besides this the main reason of the development of the grid is still not considered in these two extremes. The main aspect which demand a change of the electricity grid is the increasing demand of a more sustainable way of generating electricity. Examples of this are the increasing penetration of renewables and PEV`s on the grid. Therefore, the second aspect which is used for the design of the scenarios is the penetration of renewables on the grid. But what are interesting percentages of renewables as a ratio of the total electricity production and on what timescale these renewables are reasonable to expect? As argued in section 2.3.2 the grid is still reliable in its current state until a penetration of 30% of renewables. Around the 30% a tipping points occurs in which the conventional electricity sources cannot cope the intermittency of renewables. After the grid passed this percentage of renewables, balancing methods are needed to keep the grid stable. Knowing how the grid and the physical environment might look after this tipping point is an interesting question. A 50% penetration of renewables is a moment on which the grid and the physical environment are already significantly influenced by this tipping point. This is also a symbolic moment in which society is halfway of becoming a total green society in terms of electricity usage. Therefore 50% renewables will be used as the first amount of renewables in the scenarios.

The second amount of renewables used in the scenarios is an 80% penetration of renewables. When 80% of the energy in the world is generated by renewables it means that the world society expulses as much CO_2 as the world absorbs (Faaij et al., 2013). This can be seen as a tipping point worldwide in which the greenhouse effect is neutralized and after this the greenhouse effect can even be reversed if needed.

The final question which remains is: On which timescale can these percentages be reached? For answering this a closer look has been taken on the goals of the Dutch government. The website of the Dutch national government mentions that the goal is to make the Netherlands a greenhouse gas neutral country in 2050 (Ministerie van Economische Zaken, 2017). The goal is to repulse the greenhouse gasses by 95% in 2050. In 2016 the Netherlands produced 5,9% of their electricity with renewables (CBS, 2017a). This is used as a point of departure to interpolate on which time scale the Netherlands can produce 50% - 80% of their electricity production by renewables. As the Netherlands want to repulse their greenhouse gasses by 95% in 2050 it is assumed that the Netherlands will fully generate their electricity by renewables in 2050. Taking these statements of the Dutch government as point of departure an estimate can be made when the scenarios of 50% and 80% of renewables are reasonably achievable. By identifying where we are now and how it should be in 2050, the scenario is anchored in the past and correlate with the future goals, hence the plausibility of the scenarios is clarified. Figure 25 shows the interpolation of the renewables by firstly drawing a linear line from 5.9% in 2016 to 100% in 2050. However, transition theory argues that a transition always occurs in a s-curved line. Four parts in the transition are identified, the predevelopment, take-off, breakthrough and stabilization phase (Loorbach, 2007). Of these phases the take-off phase and the breakthrough phase are the phases where the transition goes the fastest. A possible transition concerning transition theory is shown with the orange line in figure 25. Taking transition theory as point of departure shows that 50% and 80% renewables can be achieved in the period 2035 - 2040. Of Course a transition can occur in a steeper or less steep way but if 2050 is used as a reference point to fully generate electricity with renewables the time scale 2035-2040 is certainly plausible.

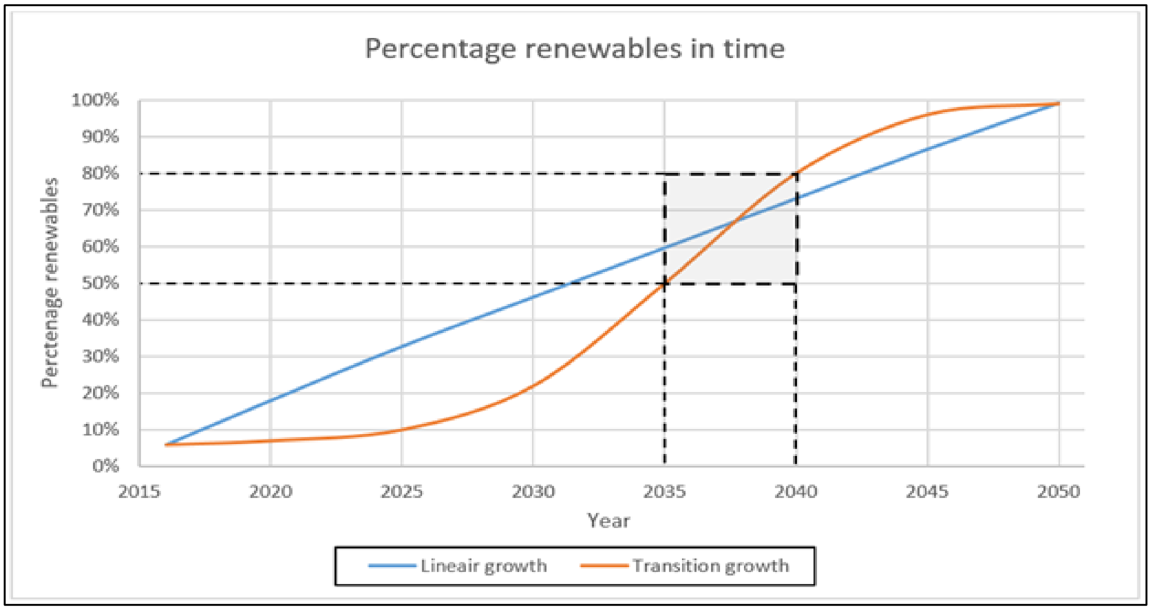


Figure 25: Interpolating the percentage of renewables

Having the scenarios anchored in the past, arguing why the scenarios are shaped based on the grid design and why 50% and 80% of renewables are an interesting input in the scenarios the scenarios can be described. The scenarios which emerge are shown in figure 26. These scenarios have a tendency to the predictive what-if type of scenario described by Börjeson et al. (2006). For example scenario 1: What if a scenario demands 50% of renewables and is organized on the central level? Besides this the scenarios also make a bifurcation between external and internal forces. The scenarios also have a normative aspect. The normative part is that an increasing penetration of renewables is needed for a sustainable future (yet not many people disagree on this). Another thing in common with the normative transforming scenario is that a change in the system is needed after 30% penetration of renewables is reached.

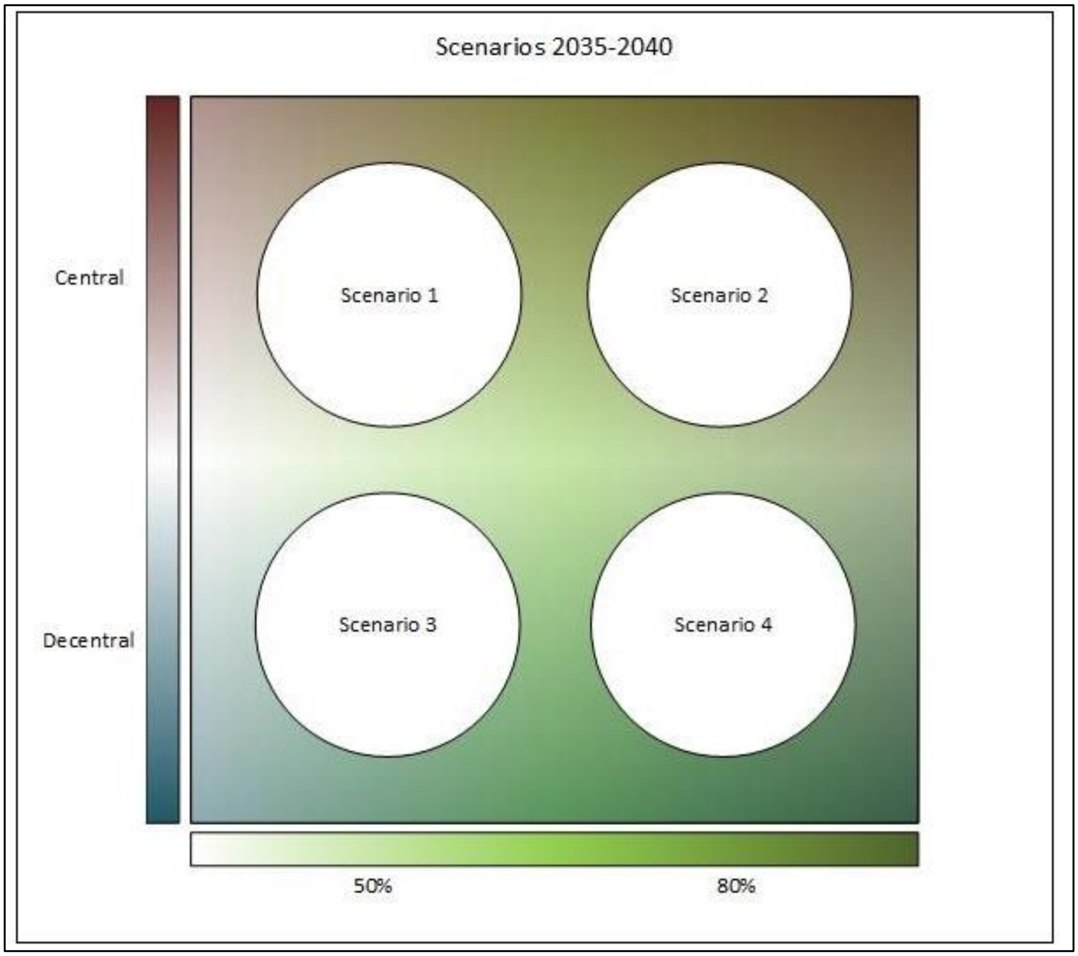


Figure 26: A scenario framework

3.3.2 Masterplan and contingency plans

Section 3.3.1. was dedicated to the construction of a framework in which the scenarios are designed. The end of this section sketched an empty framework in which the scenarios are drawn (see figure 26). The prerequisites which all the scenarios demand will be described by a desk research and will eventually be an amount of electricity demanded in 2035 - 2040. Having this as input the scenarios can be filled in. This is done by the variables described in chapter 2.3 and in the conceptual model in section 2.6. The key question for all the scenarios is: *Given the prerequisites of the framework, how can these scenarios realistically be filled in using the different variables and what does this mean for the electricity grid?* This means the spatial consequences are not a blueprint of how it should be but an example of how the scenario can look like spatially. When this is done with every scenario all the scenarios are developed which will be the first part of the results. These scenarios cover a range of the possible directions the electricity grid in the Netherlands can develop to in 2035-2040 but the scenarios are unlikely to fully appear as they are described.

Then the question remains: *What to do with these scenarios?* Because the scenarios are extremes of what is possible they probably do not resemble how the future will look like. The scenarios do resemble the range in which the electricity grid can develop. Comparing the scenarios offer insights in the uncertainties surrounding the electricity grid in the Netherlands in 2035-2040. The comparison of the scenarios will be used to identify what all the scenarios have in common and what they do not have in common. What the scenarios all have in common will be part of a masterplan and what the scenarios partly have in common will be part of contingency plans. Thus the second and last part of the results will be recommendations applicable to all scenarios (what will happen no matter what) and scenario specific recommendations (what needs to happen if). In a system which is highly uncertain and uncontrollable the masterplan and contingency plans can offer insights in the uncertainty of future developments. Figure 27 shows the masterplan and contingency plans schematically. In the red color all scenarios have a specific development in common, hence this resembles the masterplan. The green and blue colors resemble the contingency plans. Note that the contingency plans can be part of two or three scenarios. Developments which only occur in one scenario are not considered as part of a contingency plan.

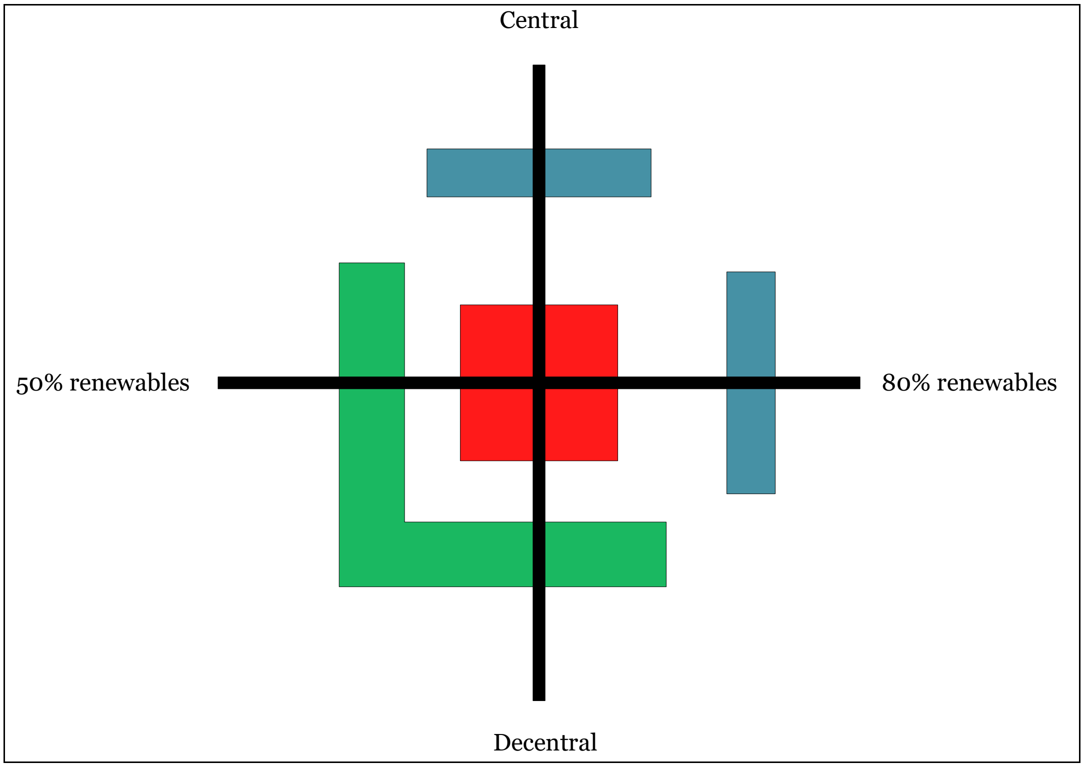


Figure 27: Masterplans and contingency plans

4. Setting the stage

This chapter focusses on the first, second and third step of the conceptual model. The first part of this chapter will describe the current situation of the electricity grid in the Netherlands and is the execution of the first step 1 in the conceptual model as shown in figure 28. First a short introduction will be given about the geographical characteristics of the Netherlands and after this the current state of all the variables incorporated in the conceptual model will be discussed.

After this external forces will be discussed. The external forces are divided in two groups. Firstly, external forces which are ought to be the same in every scenario, and secondly external forces which can be scenario specific. The scenario specific external forces can be part of the context of change, describing what forces have caused to scenario to develop towards that specific direction.

Directly below the basic analysis is described and is the first step of the conceptual model as shown in figure 28.

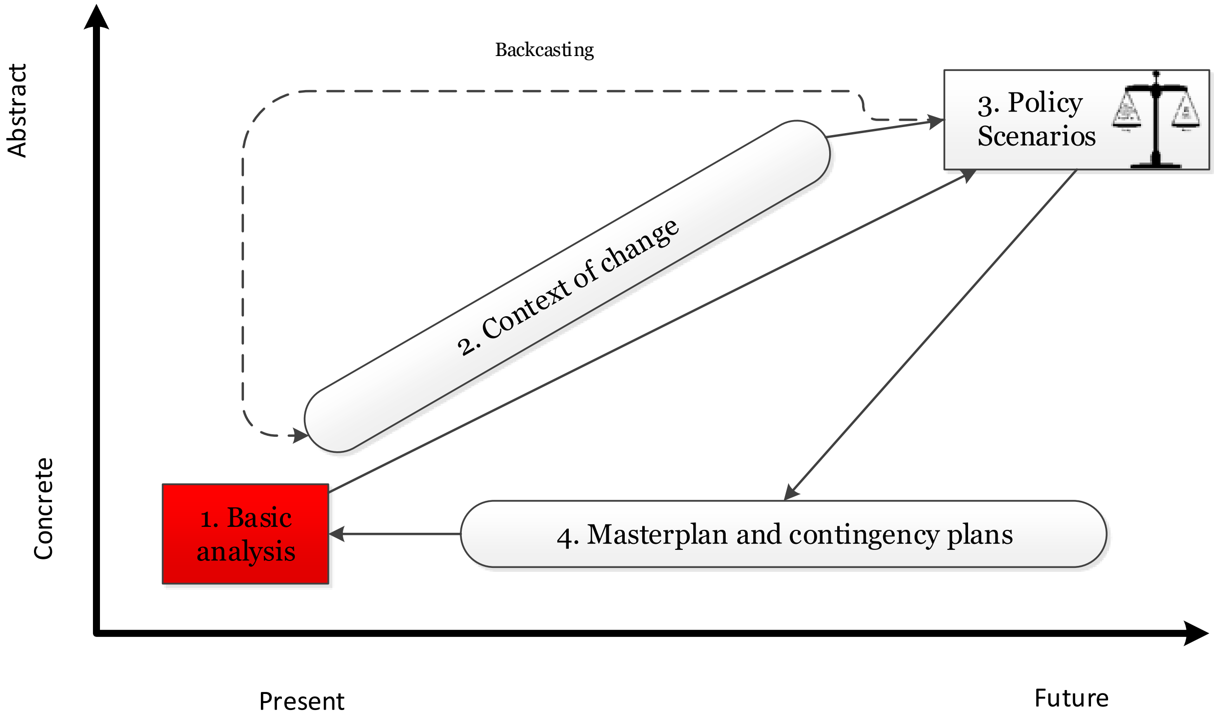


Figure 28: Step 1: Basic Analysis

4.1 Basic analysis

This section describes the current situation which is the point of departure for all scenarios. The variables discussed in the theoretical framework will be discussed but before this the geographical characteristics of the Netherlands will be discussed. This is of importance since some variables discussed in the theoretical framework demand certain characteristics.

The Netherlands is small country located in Western Europe. Its direct neighboring countries are Germany to the East and Belgium to the South. The North Sea borders the West and North of the Netherlands. Great Britain and Denmark are located on the other side of the North Sea and France and Luxembourg are also located nearby.

The Netherlands is a small but densely populated area. Consequently, on most area multiple interests are at stake. This can be clarified by for example a wind turbine park project in the northern part of the Netherlands. This project suffered from high resistance of the local population and is currently still not constructed. The highest population density is located in the western part of the Netherlands which is called the Randstad. This area is anchored by Rotterdam, The Hague, Amsterdam and Utrecht. This area is located in the western part of the Netherlands. Of all the land of the Netherlands 26% lies beneath sea level. Another 29% is prone to flooding due to the rivers our sea. The area most prone to flooding located in the west (see figure 29), also the area which has the most economic value. With 322 meter the Vaalserberg is the highest place in the Netherlands. This makes the Netherlands a very flat country. The climate is a temperate maritime climate with rainfall normally in every month. Figure 29 shows the current situation of the Dutch high voltage electricity grid in the Netherlands. Almost every area except the Wadden islands in the North are connected to the high voltage electricity grid. Several connections with the German electricity grid already have been made. Also two connections with the Belgium electricity grid, one with Great Britain and one with Norway has been installed.

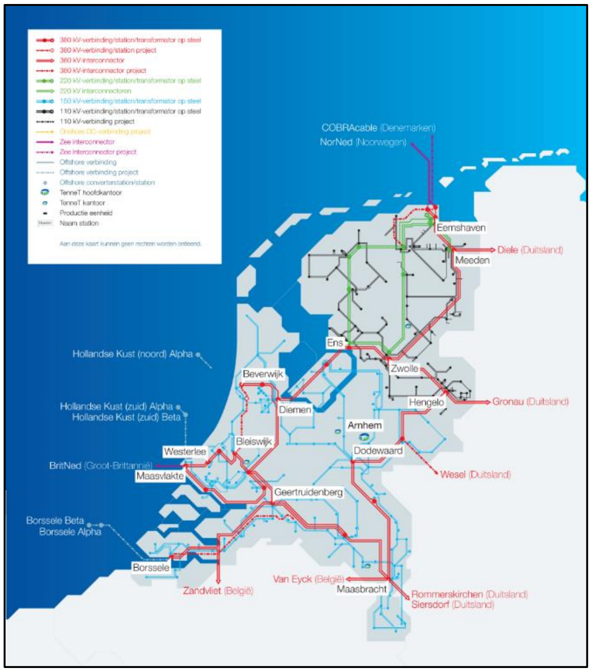


Figure 29: High voltage grid of the Netherlands
Source: www.hoogspanningsnet.com

4.2. The variables

This section will describe the current situation and presence of the variables discussed in the theoretical framework. Firstly, the current situation concerning the different types of generation methods will be addressed. Secondly the current situation of the balancing methods will be addressed and finally the current situation of the PEV will be addressed.

Conventional energy sources

The electricity grid in the Netherlands still relies heavily on conventional energy resources. Between the conventional energy sources, gas contributes most to the generation of electricity (see figure 30. The generation of gas combined is the potential electricity which can be generated. The Gas (geconserveerd) is the gas which is currently not available but can be made available when needed. These generators can be seen as a buffer for moments the current generators cannot cope the demand. The Gas (operationeel) generators are the gas generators which have been used to generate electricity. The generation of gas (operationeel) is roughly 50% (in 2017) of the total generated electricity, which makes gas by far the largest contributor to the generation of electricity. When needed gas can even contribute up to 70% of the total generated electricity (geconserveerd + operationeel). Coal still contributes significantly to the total generated electricity but with roughly 18% contributes far less then gas. Also note that the possible generation of coal decreases from 2015 to 2017. This coincides with the goal of the Dutch government of completely disbanding coal generators in 2030 (Walle, 2017). However, a combination of coal fired power plants and CCS is considered as an option in the Netherlands (Ministerie van Economische Zaken, 2016a). Currently the feasibility of this combination is being researched and some pilot projects are on the verge of being started (EBN & GasUnie, 2010).

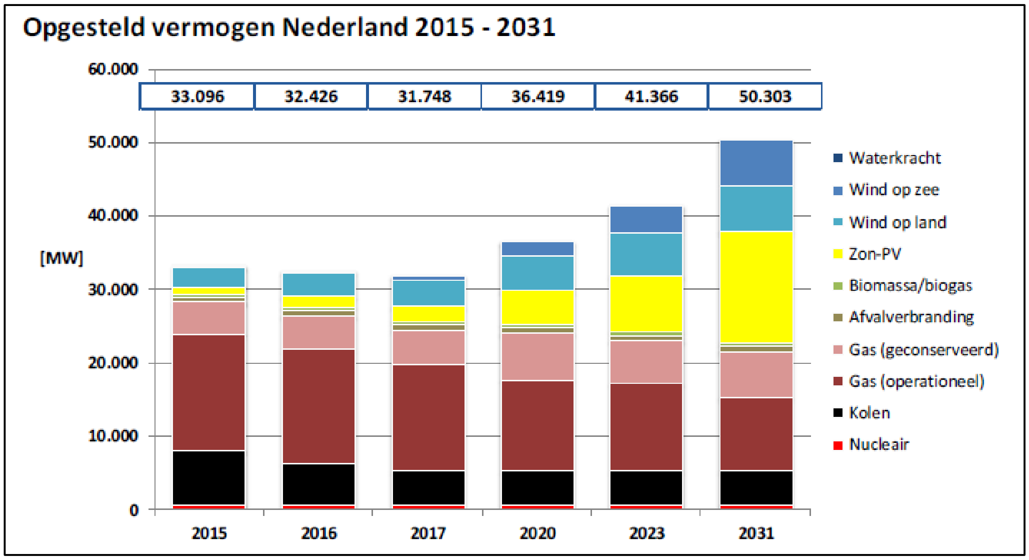


Figure 30: Composition of the potential output of the electricity generators in the Netherlands Source: Tennet (2016)

Renewables

The contribution of renewables to the total generated electricity is still small in the Netherlands. Figure 30 however shows that the last two years the contribution of renewables has slightly increased. In 2016 renewables contributed for 12,5% to the total electricity generated (CBS, 2016). Wind energy contributed the most to renewable energy by generating 7% of the total electricity in 2016 (CBS, 2016). Solar energy contributed for less to renewable energy by only generating 1,3% of the total electricity demand (CBS, 2016). The remaining percentages of renewables are contributed by other generation methods, of which biomass contributed the most. It is however debatable if biomass is a renewable energy source or not. If only wind and solar are considered renewables the penetration of renewables was 8,3% in 2016.

But as already mentioned there is a shift going on in which renewable electricity increases annually. In comparison with 2015, the generated electricity of solar pv increased with 39% in 2016 (CBS, 2016). Figure 31 shows the current solar parks present in the Netherlands. Despite some solar parks are already present, in comparison with wind turbines they still contribute little to the total renewable output. Also almost every of the current active solar parks are small. Only one solar park, the solar park in Delfzijl, is generating more than 6 MW (ROM3D, 2018). In total the current active solar parks generated approximately the same amount as 15 wind turbines. Most of the current solar pv is generated by individual households on the “lokale distributienet”.

Wind turbines contribute much more to the total output of renewables. The majority of wind energy is currently generated onshore (see figure 32). Figure 32 shows the distribution of wind turbines in the Netherlands. Wind turbines are mainly placed near the shore, where there is more wind present than inlands. There are also plans to build large off shore wind turbines parks, in which an international alliance has pointed out the Dogger bank, a shallow part in the North Sea, as a potential place to construct large of shore wind turbine parks. This area is located north east of the Netherlands.

Figure 31: Realised large solar pv projects in the Netherlands Source: www.rom3d.nl

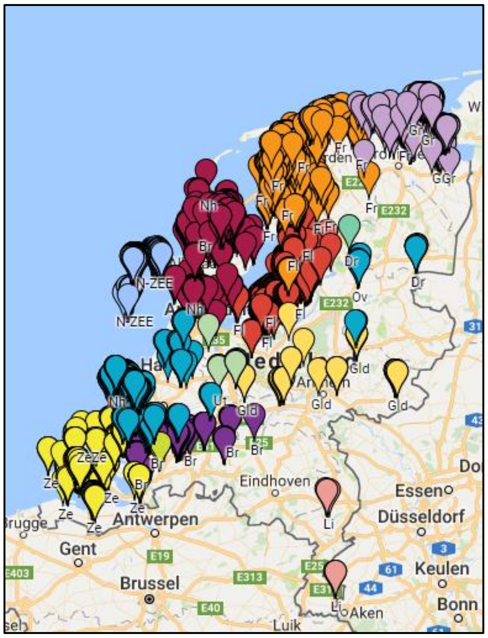


Figure 32: Realised contruction of wind turbines in the Netherlands
Source: www.windenergie-nieuws.nl

Energy storage

As the penetration of renewables in 2016 was only 8,3% still not storing methods are needed. This also explains the absence of storing energy on a large scale in the Netherlands. However due to the increasing penetration of renewables the (planned) pilot projects are in abundance. An example is the pilot project PowerMatching City II. In this pilot project a micro smart grid was created in which several DSM appliances where combined with solar pv and the PEV as a storing method (Agentschap NL, 2012).

Different techniques like for example, large hydro electrolyze to create hydrogen is considered as well as small storage with batteries in households. The current situation is that energy storage contributes little to the current electricity grid but many potential ways of storage are considered for in the near future.

Demand side management

In the theoretical framework demand side management was divided in 4 categories: 1) Energy Efficiency (EE), 2) Time of Use (TOU), 3) Demand Response (DR), 4) Spinning Reserve (SR). The current situation in the Netherlands concerning DSM will be analyzed by these four aspects.

Until 1990 energy consumption and economic growth where connected with each other. The energy consumption followed the economic growth (CPB & PBL, 2015). The energy intensity dropped after 1990, which has been caused by energy savings measures and energy efficiency. This meant that a decoupling took place between the economic growth and the energy consumption.

PEV and Vehicle to grid

The electric vehicle has made a spectacular development in the last four years in the Netherlands. At the end of 2013 there were approximately 10.000 electric vehicles in the Netherlands (Ministerie van Economische Zaken (2016b). This number increased to 123.542 electric vehicles on 31th of December 2017 (Netherlands Enterprise Agency, 2018). In the Netherlands are approximately 8.300.000 cars, which means only 1.5% of the total cars are electric vehicles (CBS, 2017c). Despite PEV ownership has grown massively in a relative way, the total ownership of PEV is still a very small part of the total owned cars in the Netherlands.

The Netherlands is currently executing a policy in which the charging infrastructure network should not be a restricting aspects of the penetration of electric vehicles. This made the charging network increase from approximately 13.000 charging poles in 2013 to 80.000 in 2017 (Netherlands Enterprise Agency, 2018). Most of these charging poles are located in the Randstad but the infrastructure is rapidly expanding towards other regions as well. Besides the normal charging poles, also a network of fast charging poles in constructed rapidly (Ministerie van Economische Zaken, 2016b). These fast charging poles are mainly constructed on strategic positions, which is mostly next to highways.

4.1. Historic, current and future electricity demand

Until the year 1996 there was a direct relation between the growth of energy demand and the growth of the gross domestic product (GDP) of the Netherlands. If the GDP grew with 3% the energy demand would grow with approximately the same. This would make the demanded electricity in 2035- 2040 easy to predict. However, after the year 1996 a decoupling took place between the GDP and the energy demand (Matthijsen & Aalbers, 2015). This was caused by energy efficiency measures such as isolating houses. Between 1996 and 2015 the energy demand stayed approximately the same with a drop in demand in 2008 to a slow recovery to the original demand in 2012. In the same period the GDP grew around 30% (Matthijsen & Aalbers, 2015). The urge of a more sustainable future started to become visible in the electricity industry. Currently and in the future energy efficiency measures are still an important aspect in the quest to a more efficient energy system. It should be noted that this trend is about energy and not electricity. Electricity is a part of the whole energy demand. Different types of fuel for automobiles for example are part of the energy demand but are not part of the electricity demand (except the PEV). Though the other aspects of the total energy demand do not directly influence the electricity demand they are nonetheless worth mentioning. This is because an electrification of the Dutch society is slowly taking place and shifts from the other parts of the energy demand are shifted to the electricity demand side. For example, the PEV which replaces the conventional fossil fuel powered automobiles. TenneT, the Dutch national electricity provider, makes an annual estimation of the future electricity demand of the Netherlands as shown in figure 33 and figure 34. Two things are notable in these figures. Firstly, the large difference between the reference scenario (referentiescenario) and the high scenario (hoog scenario). In 2030 the difference of the total annual production is approximately 20% between the reference scenario and the high scenario. The main causes for this difference are contribution of heat pumps and PEV's to the total electricity demand (TenneT, 2016). The heat pumps will replace the conventional heating source of houses, which is gas and the PEV will replace the fossil fuel powered vehicle. In both scenarios there is an increase in heat pumps and PEV's but in the high scenario the increase is explosive compared to a moderate increase in the reference scenario. In 2015 there were approximately 90.000 PEV's registered

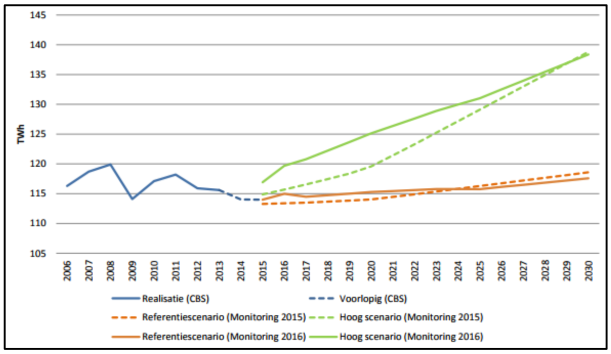


Figure 33: Predicted demand untill 2030
Source: TenneT (2015)

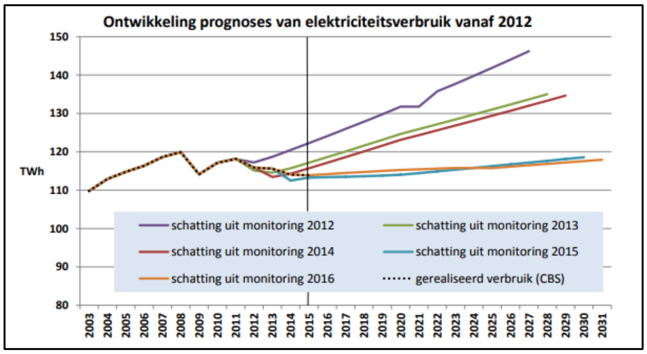


Figure 33: Predicted demand untill 2031
Source: TenneT (2016)

in the Netherlands. As the 2016 scenarios are still a prediction of what will happen, Tennet assumed an explosive growth of the PEV that year in the high scenario. This is the reason why the high scenario starts with a higher demand of electricity compared to the reference scenario. The second notable fact is shown in figure 34 which shows the development of the electricity demand between 2012 to 2016. These predictions are the reference scenarios in figure 33. The prediction is decreased year after year with 2012 showing a predicted electricity demand of approximately 145 Twh in 2026 whereas the prediction of 2016 shows a demand of approximately 115 Twh in 2026. This is a difference of 26%. Based on the previous facts, the range of the electricity demand in 2035 -2040 can be extrapolated. Taking into account the prediction of the electricity demand in the period 2012 – 2016, and the annual adjustment downwards the lowest prediction can be set. It is assumed that this continuous drop in the annual prediction will continue and that the annual demand will drop in such a way that the total demand will stay flat until the period 2035 – 2040. This means the lowest prediction in electricity demand will be 115 Twh. To determine the highest prediction of electricity demand in 2035 -2040 the high scenarios of 2015 and 2016 in figure 33 will be used. Based on the annual increase in demand and the years remaining to reach the period 2035 – 2040 the maximum demand can be extrapolated. Based on the extrapolation the maximum demand of electricity in the period 2035 – 2040 will be set on 150 Twh.

4.2 External forces

This section will discuss the relevant external forces. These are forces on which the policy scenarios can have little to no influence. The first part will consist of general external forces, effecting the scenarios in a similar way. The second part will consist of scenario specific external forces. These forces are responsible for the development towards the policy scenario in the next chapter.

4.2.1 General external forces

The general external forces are the forces which are evenly present in all scenarios. These external forces are ought to be predictable and therefore used as one single input for all scenarios. Although these forces are not the explanation of the differences between the scenarios, they are worth mentioning. Despite these forces are ought to be predictable it is not impossible that they change drastically. When these external forces change drastically the value of the scenarios automatically decreases.

Demographic developments

The demographic development is considered a stable factor in the future demand of electricity. Currently the Netherlands has 17,15 million inhabitants (CBS, 2017b). The prognosis is that the Dutch population will grow to 17,8 million inhabitants in 2030 and that the Dutch population will continue growing to 18 million inhabitants in 2035 (Schoots et al., 2016). Because TenneT (2016) uses this input for the calculation of the electricity demand this input will also be used in the scenarios in this thesis. The development of the inhabitants of the Netherlands will not influence the electricity demand described in the previous section because this development is already incorporated in this prognosis. Another aspect considered in this prognosis is the growth of the amount of households. A systematic trend in the Netherlands is the diminishing of the household sizes. This trend is expected to continue in the future (Schoots & Hammingh, 2015). A diminishing of the average household size in combination with a growth in population means the total amount of households will grow. As a larger household is more energy efficient per person than a few single households this will also affect the future total electricity demand in the Netherlands. Schoots & Hammingh (2015) predicts that the total amount of households will grow from 7,7 million in 2015 to 8,1 million in 2020 and to 8,4 million in 2030. Taking into account these numbers the expected amount of households in 2035 will be 8,5 million. This growth is also already incorporated in the predicted electricity demand by TenneT (2016) in the previous section.

Economic growth

Because the economic growth can have a significant impact this section will clarify what the economy is expected to do in the scenarios. The economic growth is again based on the Nationale energieverkenning 2015 (Schoots & Hammingh, 2015) and the Nationale energieverkenning 2016 (Schoots et al., 2016). Schoots & Hammingh (2015) state that the average economic growth of the Netherlands, in the period of 2015 – 2030, will be 1,75% per year. Schoots et al. (2016) elaborate on this by describing the average expected growth in the period of 2030 – 2035, which is 1,5% per year. Notable is that both the period of 2015 – 2030 and 2030 – 2035 do not reach the economic growth of the period before the economic recession, which started in 2008. The average economic growth in the period of 2000 – 2008 was 2,3% per year. The lower economic growth in the period after the economic crisis can be explained mainly by the aging of the Dutch population (Schoots & Hammingh, 2015).

4.2.2. Scenario specific external forces

The scenario specific external forces are of particular interest since they are they can explain the differences between the scenarios. The first part of the section will consist of the influence of scenario variables (Decentral/ Central and 50% - 80% renewables) on the electricity demand. It is debatable if these aspects are part of the external forces. However, to be able to develop the scenarios in the next chapter it should be clarified what these variables mean for the scenarios.

The second part will consist of external forces which are relatively unpredictable and will influence every scenario in a specific way. These external forces are the drivers towards a specific scenario developed in the next chapter.

Central or decentral

Because a centralized or decentralized electricity grid is part of the scenarios this section will elaborate on what this could mean for the electricity demand. A study of Matthijsen et al. (2015) for the Centraal Planbureau voor de Leefomgeving, a governmental organization which among other things makes prediction about future developments, has made this distinction and what this means for the total energy needed. The aim of this study was to sketch what a central or decentral oriented energy supply would mean for the demand as a whole. It is self-evident that a decentralized energy grid focusses on decentralized generation methods whereas a centralized energy grid focusses on centralized generation methods. Matthijsen et al. (2015) also state that in a decentralized aim the energy efficiency measures will develop faster than in a centralized aim which would also imply a lower electricity demand. On the other hand, a more decentralized scenario empowers a faster electrification of the society compared to a decentralized scenario (Matthijsen et al., 2015). Two developments which could contribute significantly to this electrification where given in the previous section, namely heat pumps and PEV's. A faster electrification of society would imply a rising electricity demand. In this thesis the assumption is made that the impact of a faster electrification outweighs the energy efficiency measures which would be taken on the decentral level. In a central scenario the electrification of the society would go on an average pace. The PEV and the heat pump still increases in numbers but not as fast as in a decentral scenario. The electricity demand will rise much slower or will even decrease if the energy efficiency measures outweigh the aspects increasing the electricity demand. This means the central scenarios will have a tendency towards the reference scenarios whereas the decentral scenarios will have a tendency towards the high scenarios of TenneT (2016). The faster electrification of society is visualized in figure 34 and figure 35.

Figure 34 shows a distribution of different energy sources before a decentralization effect and figure 35 shows the effect on this distribution after a decentralization effect

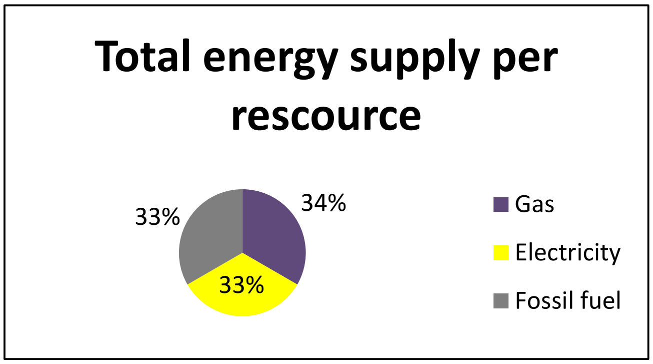


Figure 34: Distribution of energy sources before a decentralization

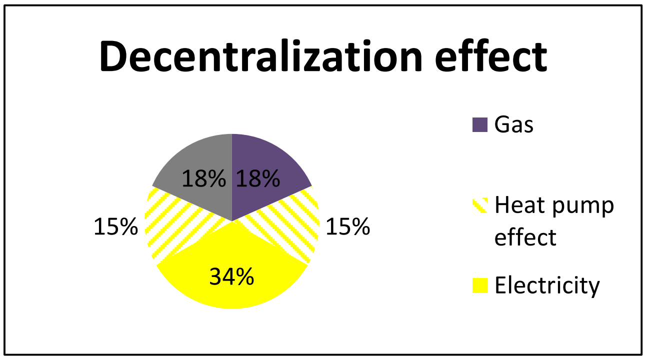


Figure 35: Distribution of energy sources after a decentralization effect

Fifty or eighty percent renewables

The percentage renewable energy is the second aspect in the scenario framework. This part will elaborate on what this would mean for the scenarios and what assumptions are made. It is assumed that the percentage of renewables resembles the relative importance of sustainability for the Dutch society. In the 80% renewables scenarios sustainability is found as one of the main drivers of politics and policies. These policies enable a faster penetration of renewables in the total electricity generation. Because a higher penetration of renewables entails larger intermittency problems of renewables other aspects supporting the penetration of renewables are also part of the grid. An example of this is the concept of the Vehicle to Grid (V2G), in which the PEV also functions as a battery for storing capacity and support of the grid on peak demand moments. V2G will be made mandatory via policy to support the high penetration of renewables. Electrification in the 80% renewable scenarios will also go faster than in the 50% renewable scenarios because the sustainable policies, as one of the main policies, supports a shift from conventional energy sources towards the sustainable electricity sources (see figure 36 and 37). The example of the PEV replacing the conventional fossil fuel powered vehicle is again an example of this.

In the 50% renewable scenarios, policies concerning sustainability are present but are not considered as one of the most important policies. The electrification of the society will still take place but in a slower pace as in the 80% renewable scenarios. Renewables still penetrate deeper into the electricity market but not as fast as in the 80% scenarios. Consequently, other aspects supporting the penetration of renewables are not as drastic as in the 80% scenarios and the electrification will also go slower. The PEV becomes a more common way of transportation but will not dominate the market. Also the concept of V2G, as one of the possible policies, will not be mandatory but voluntary. Due to the slower electrification in the 50% renewable scenarios the total electricity demand has a tendency towards the reference scenarios whereas the 80% renewable scenarios have a tendency towards the high scenarios of TenneT (2016).

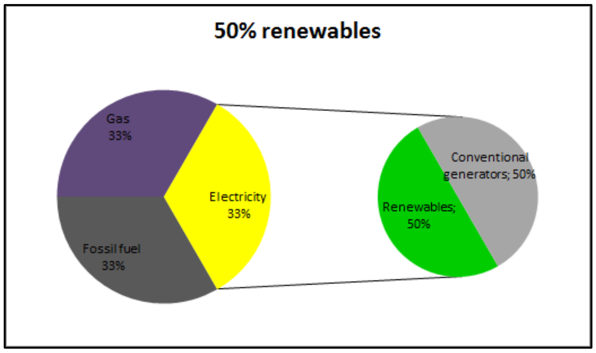


Figure 36: 50% renewables and the distribution of energy sources

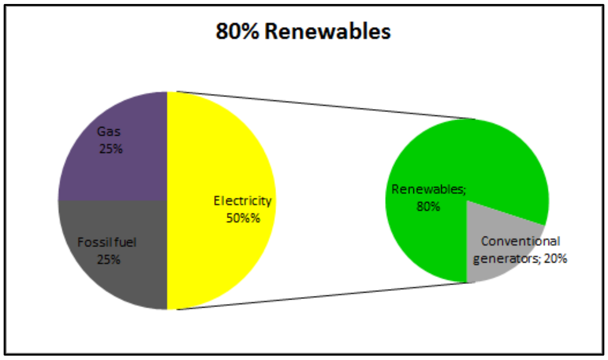


Figure 37: 80% renewables and the distribution of energy sources

External aspects influencing the scenarios

This section will elaborate on the external factors influencing the electricity demand. These factors will be used as a fixed influence on all the scenarios. As the section; "*From historic development to future demand"* is based on the document TenneT (2016) and TenneT (2015) these documents will also be used to determine the factors in this section. These documents, in their turn, based the prediction of electricity demand on the annual national energy exploration (Nationale Energieverkenning) done by the Dutch government. As the documents of TenneT are based on the national energy exploration of the previous year the documents of 2014 and 2015 will be used to determine the fixed factors in the scenarios. The consecutive factors which will be discussed in this section will demographic developments, macro-economic developments, energy market and emission trading.

Energy market and emission trading

Because the future electricity demand is highly dependent on developments of other energy sources this will section will elaborate on the expected prices of oil, gas, coal, CO_2 emission rights and the price of electricity. Electricity can replace other energy sources or vice versa if the relative costs of electricity and another energy source change from each other. If for example electricity becomes relatively cheaper compared to oil, driving an PEV might become a more economical alternative. The prognoses in this section are based on Schoots et al. (2016). Figure 38 and figure 39 show the predicted price development of consecutively oil, gas, coal, CO_2 and electricity. The predicted oil price will rise approximately 90% in the period 2015 - 2035. Gas prices will rise approximately 50% and the coal prices around 30%. Compared to these conventional energy sources electricity rises an approximate 45% in the period of 2015 – 2035 which makes the price increase around average. What is notable in these figures is that the range of the price of all energy types is relatively low compared to the range of the price of the CO_2 emission rights. The estimation within the bandwidth is that it will rise approximately 400% in costs but the upper bandwidth can go up as much as 1200% in the period 2015 – 2035. Because both the coal and gas power plants emit $CO_{2,}$ their economic viability can be severely influenced by an increasing price of CO_2 emission rights.

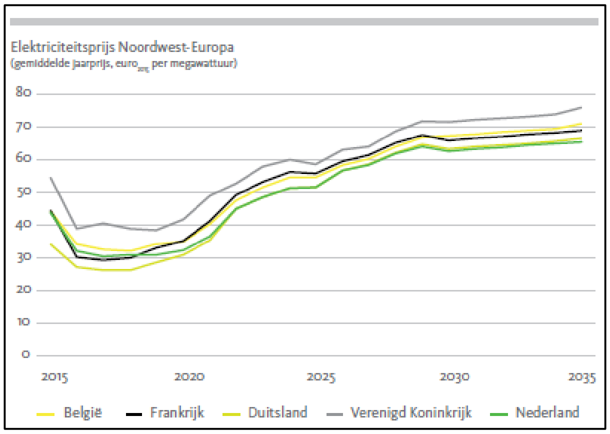


Figure 38: Predicted electricity prices in North-West Europe Source: Schoots et al. (2016)

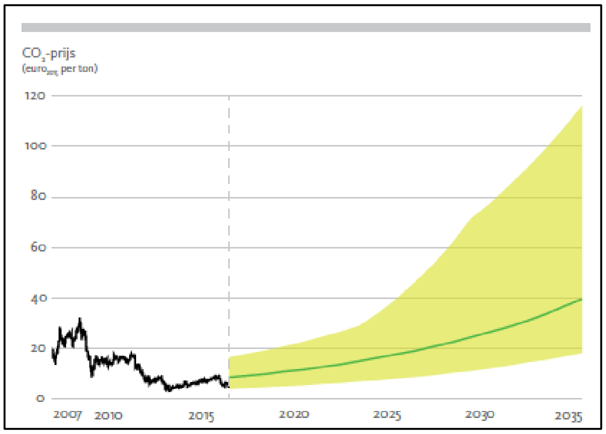


Figure 39: Predict CO2 emission price in Europe Source: Schoots et al. (2016)

What will the electricity demand be in 2035-2040?

Taking into consideration the different circumstances for the different scenarios, not one single electricity demand can be determined in the period 2035 – 2040. This section will determine what the electricity demand will be in every individual scenario. All the scenarios will have a demanded electricity between the range of the high demand scenario and the reference demand scenario as described in figure 33. Depending on the scenario specific characteristics the electricity demand will tend more towards the upper or lower part of the bandwidth. These characteristics consist of the two variable used as input for the scenario (central or decentral orientated electricity grid and 50% or 80% renewables). It has firstly been argued that a decentralized electricity grid encourages a faster electrification of society compared to a centralized grid. Or argued another way around; If decentralized developments gain momentum a faster electrification of society takes place. The other variable is the percentage of renewables feeding the electricity grid. In the 50% scenarios the environmental policies are not of particular importance compared to the 80% scenario where the environmental policies are one of the most important policies, which explains the different percentages between the scenarios. This however, does not explain why the electricity demand is higher in the 80% scenario. The increase in electricity demand is caused by the faster replacement of fossil fuels cars and gas fired heating by PEV`s and electric heat pumps which is encouraged by these environmental policies. Taking into account these inputs the electricity demand can be determined. Scenario 1 has a central orientated electricity grid and 50% renewables and therefore has the lowest electricity demand. The annual electricity demand in scenario 1 will be 120 TWh. Due to the decentralized focus but only limited development in the renewable penetration scenario 2 will have an average annual demand of 135 TWh. Scenario 3 is again focused on a centralized grid but has a high penetration of renewables which is 80%. Therefore, the annual electricity demand in scenario 3 is also average with 135 TWh. Scenario 4 has a decentralized focus and 80% renewable penetration which makes this scenario the most electricity demanding. This scenario has an annual electricity demand which tends to the upperpart of the bandwidth and is set on 150 TWh

4.3 General findings

This section will describe general findings which will be used as point of departure for the scenarios. The general findings are aimed on the variables mentioned in the theoretical framework. These findings are based on the data collected from the interviews and the desk research.

4.3.1 Conventional energy sources

The Netherlands are part of an alliance which has the goal to completely phase-out coal fired generators in 2030 (Walle, 2017). Consequently, the coal fired generators have a high chance of disappearing from the picture in the Netherlands. This will mean that in most of the scenarios the coal fired generator will be disappeared. However, a combination with coal fired power plants and CCS is still an option (Ministerie van Economische Zaken, 2016a). If CCS is applied in a scenario this will be combined with a presence of coal fired power plants. Another consequence of CCS was pointed out by interviewer 1 and 2. If CCS is applied then this will slow down the developed of renewables for two reasons. Firstly, because as pointed out “money can only be spend once”. If the budget for the energy transition is used for CCS, then this money cannot be spend on renewable energy sources. Secondly even if the budget could be doubled then this would still slow down the transition because when CCS is applied you need conventional energy sources to connect it to. CCS is an application which has a higher potential when applied in a central oriented scenario (CPB & PBL, 2015). If the coal fired power plants will disappear then the gas fired power plants will automatically fill in the remaining part of the of the conventional energy generation. Consequently, the chance of having gas fired power plants. As gas power plants are not mentioned in combination with CCS in the analyzed documents it is assumed that gas power plants will not be present in combination with CCS. As coal fired power plants have a high probably of disappearing from the picture, the gas fired power plants have a high probability of still being present. Interviewer 1 also pointed out that with an adjustment in the gas fired power plants, these power plants can also generate electricity with hydrogen. This will increase the chance of having the gas fired power plants in the future picture, but converted to hydrogen power plants.

4.3.2 Renewables

As mentioned in the theoretical framework, different types of renewables are suited for different parts of the grid. Consequently, a central/ decentral oriented electricity grid will also influence the types of renewables. A central oriented electricity grid will have more wind turbines on sea whereas a decentral oriented electricity grid will have more wind turbines on land (Kool & Manders, 2015). Furthermore, CPB & PBL (2015) states that a decentral oriented grid will have more solar pv than a central oriented electricity grid. This coincides with the theoretical framework which mentions solar pv to be a more decentral generation method and wind turbines a more central oriented generation method.

The theoretical framework also states that individual wind turbines should be connected to the “regionale distributienet” and wind turbine parks should be connected to the “transportnet”. Interviewer 2 points out that this is not completely true. A wind turbine park in the area Drentse Monden/Oostermoer, which is on the verge of construction, is going to be connected to the “regionale distributienet”. This wind turbine park is going to generate between the 150 – 180 MW which is above the maximum of 100MW mentioned in the theoretical framework. However due to the presence of multiple “regionale distributienetten” in the area the generated electricity can be divided over multiple station as pointed out by interviewer 2. The reason for connecting this park to the “regionale distributienet” is that it is more cost efficient to connect the wind turbine farms to the lower part of the grid as all electricity needs to flow downwards to reach the consumer. Another issue with wind turbine parks on land is that these parks often face resistance from local residence as it is the case with the wind turbine park in Drentse Monden/Oostermoer as well. Furthermore, interviewer 2 points that currently large solar farms have to compete with other types of land use. Solar Parks are often constructed outside urban areas where land is often used for agriculture or the development of nature. This is problematic for the penetration of solar pv as the Netherlands is a densely populated country in which also agricultural land and nature is scarce. Only when the competition of land use can be overcome, solar pv has a chance of penetrating into the electricity generation in the rural areas. Land use competition is a far lesser problem with wind turbines has they go into the height instead of the width.

4.3.3 Balancing methods

Three different types of balancing methods have been recognized. Firstly, the storage of electricity, secondly demand side management and thirdly internationally aimed grid infrastructure expansion. In general, there can be stated that as the renewables penetrated further into the electricity generation, balancing methods will be needed more in the electricity generation system, as stated in the theoretical framework. This will mean that balancing methods will play a bigger role in the 80% scenarios. Between the central and decentral oriented scenarios there was also a different preference of the type of balancing method. As mentioned by Albadi & El-Saadany (2010) geographical dispersion of renewables is an important way of keeping the grid stable. Both interviewer 1 and 2 stated that international grid expansion is an important way of dealing with the intermittency of renewables. Because the Netherlands is a small country, expanding the grid size implicitly implies a better connection with neighboring countries. As this was both mentioned by interviewer 1 and 2 this will be an important way of managing grid stability. A difference between interviewer 1 and 2 was the preference of DSM or electricity storage. Interviewer 1, which was aimed at collecting data for the central scenarios stated that energy storage was another important aspect of the grid. DSM was hardly mentioned besides energy efficiency. On the other hand, interviewer two clearly mentioned that besides a better international connected grid, DSM will be the most important way of balancing the grid. The reason for this was simply because DSM is cheaper than storing electricity.

4.3.4 PEV

As mentioned in the previous chapter the penetration of the PEV is dependent on the specific characteristics of the scenario (central or decentral and 50% or 80% renewables). A decentral focus will cause that the penetration of the PEV will go faster than a central focus (CPB & PBL, 2015). It is also implied that environmental friendly policies will play a bigger in the 80% renewable scenarios than in the 50% renewable scenarios. These environmental policies are the cause of a faster penetration of renewables, but also the cause of stimulating environmental friendly cars replacing the conventional petrol fired cars. The penetration of the PEV per scenario is shown in table 4.

Scenario	Percentage PEV
Scenario 1 : central , 50% renewables	20%
Scenario 2: central , 50% renewables	50%

Scenario 3: decentral, 50% renewables	50%
Scenario 4: decentral, 80% renewables	80%

Table 3: Penetration of the PEV per scenario

4.4 The scenarios

In this section the context of change is described and the scenarios are developed. The context of change is the storyline of the scenarios to give insights in which external developments have caused the electricity grid to develop towards this specific scenario. The order of the scenarios is the same as the scenarios in figure 26. First the central scenarios will be described in which the 50% renewables scenario goes first and after this the 80% renewables scenario. After this the decentral scenarios will be described of which the 50% renewables scenario goes first again and after this the 80% renewables scenario will be described. Step 1 of the conceptual model has been executed and this chapter is the execution of step 2 and 3 of the conceptual model as shown in figure 40. The end of every scenario will summarize the presence of every variable by visualizing them in speedometers. The scenarios are used as a tool for comparison in the next chapter.

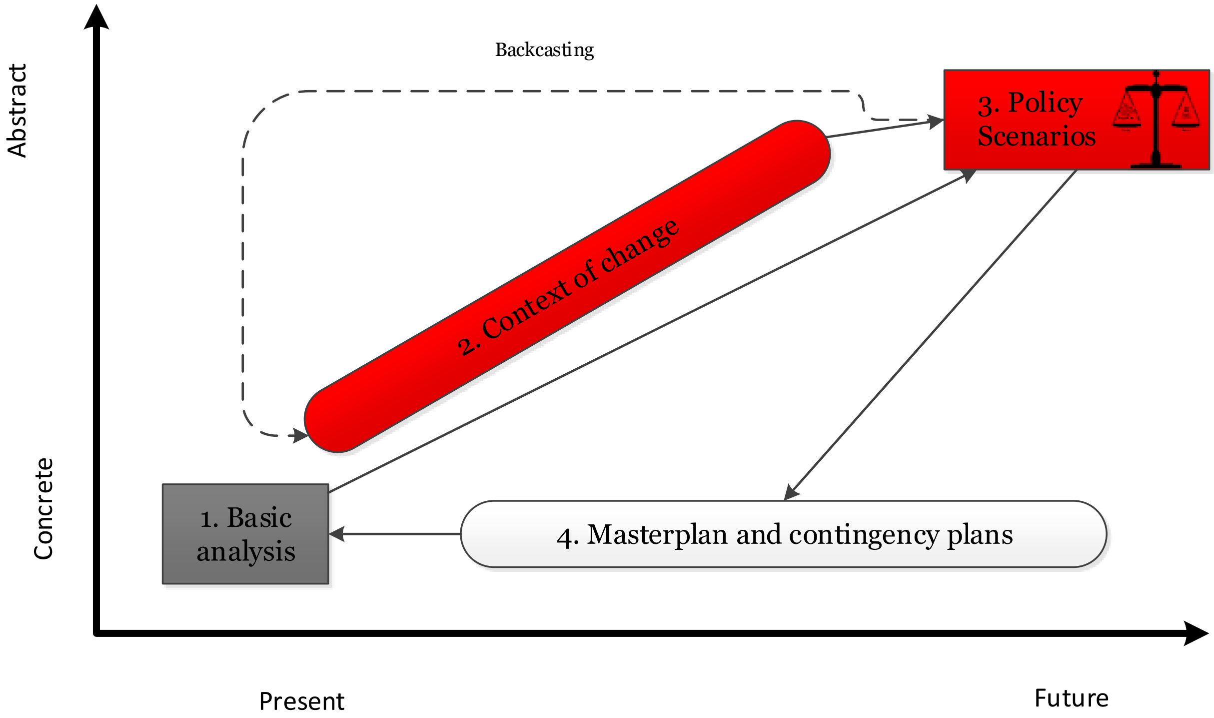


Figure 40: Step 2 and 3 of the conceptual model

4.4.1 Scenario 1: Empowering the North Sea

Context of change

The national government has taken control over the energy transition. Together with TenneT, the Dutch national grid operator, large projects are realized which contribute to the sustainability of the electricity grid. Due to the large projects the grid is highly centralized. The difference on international legislation has not been overcome, hence the electricity trading with neighboring countries is only limited. This has a significant influence on the stability of the relatively small electricity grid in the Netherlands and the intermittency problems which come along with this. To keep the electricity grid stable, the energy transition has slowed down. Other central solutions are sought, in which CCS plays and important role together with large central energy storage. The international aspect which has the most influence on the development of the electricity grid is the European agreement on a high CO_2 emission price which has made CCS a profitable solution. Local and provincial governments are only involved in a limited way at the energy transition. Also the Dutch society is only involved passively in the energy transition, having no particular interest in a fast energy transition. In the contrary, resistance against onshore wind parks have halted further development of onshore wind energy and also rooftops are not excessively used.

The electrification of the Dutch society has only progressed slowly which has caused only a small increase in the annual electricity demand from 115 TWh to 120 TWh. Due to the low interest of society petrol fired cars still a major role in the daily transportation together with gas heating.

The variables

Conventional energy sources

With 50% conventional energy sources still play an important role. Within the conventional energy sources a shift as taken place from a more gas based electricity generation towards a fully coal based generation. The goal of the Dutch government to completely phase out the coal fired power plants before 2030 has not succeeded. In the contrary, electricity generated by coal power plants has increased. This has been caused by the implementation of CCS, which is especially suited for coal fired power plants. CCS is an application which is most efficiently applied on a grid with still a significant amount of large central conventional generators. Still a large amount of conventional generators is needed because CCS demands high initial costs which can be most effectively spread when CCS is done on a large scale. Hence this scenario, with a central focus and still a significant amount of conventional generators suits CCS well. CCS is an application which EBN & GasUnie (2010) points out that in the western and northern parts of the Netherlands or especially suited for CCS. In both regions empty gas caverns are mainly considered as options for CCS. The difference between the regions is that in the western part of the Netherlands CCS can be applied mostly offshore and in the northern part of the Netherlands CCS can be applied mostly onshore, in the empty gas caverns. Figure 41 shows the possibilities of offshore CCS in the western part of the Netherlands. Two pipelines are proposed which depart from Amsterdam and Rotterdam. The first gas cavern which will be used are the closest to the shore but as CCS increases it will develop more to the North of the Netherlands. Figure 42 shows the onshore CCS possibilities in the Northern part of the Netherlands. The Eemshaven is a region where electricity is generated on a large scale. It also has a large and some smaller gas fields nearby. Although there are still many conventional electricity generators, the electricity system in the Netherlands has decreased significantly in terms of CO_2 expulsion. Because the focus of conventional energy sources shifted to coal, gas fired generators are almost completely outsourced. The building of gas generators itself will not completely disappear out of the landscape. The newest gas generators will be transformed to a hydrogen generator. The older generators will disappear from the landscape.

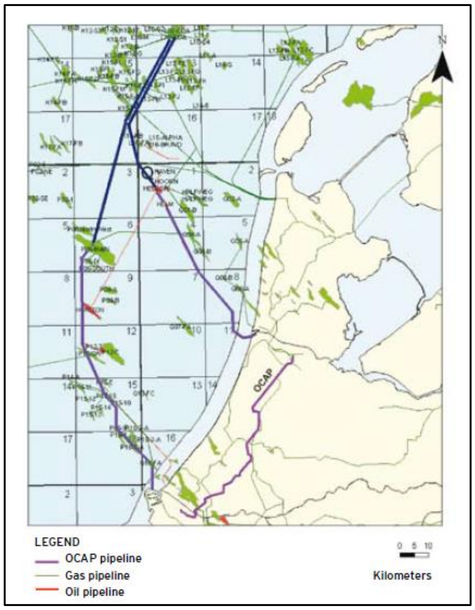


Figure 41: CCS in the North Sea
Source: EBN & GasUnie (2010)

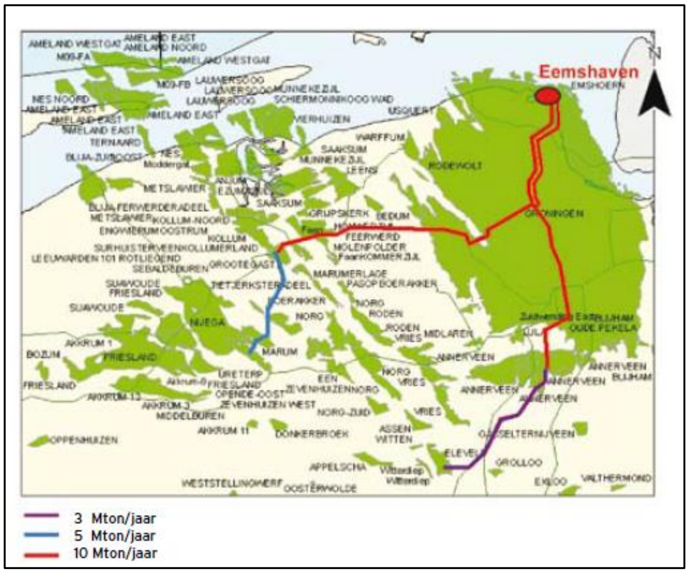


Figure 42: CCS in the northern part of the Netherlands
Source: EBN & GasUnie (2010)

Renewables

Renewables have penetrated to a 50% share in the total generation of electricity. Especially the technological developments on wind turbines have increased significantly. This has caused wind turbines to be the main source of renewables. Due to the passive involvement of the Dutch society in the energy transition the resistance against onshore wind turbines has continued. This has caused onshore wind turbines to only contribute in a limited way to the energy transition. Mainly offshore wind turbine parks have grown in numbers and size and are the main contributors of renewable energy. Offshore wind turbine parks are constructed close to the shore of the Netherlands because the loss of transporting the electricity is minimized this way and international collaboration is limited. Matthijsen et al. (2018) developed a scenario study aimed on the possibilities of arranging the North Sea. Especially the spatial arrangement of the scenario “pragmatisch duurzaam” suits this scenario because this scenario takes into account a large share of wind energy with a limited international collaboration. Figure 43 shows this possible arrangement in which all the bright yellow areas are possible wind turbine park areas in the

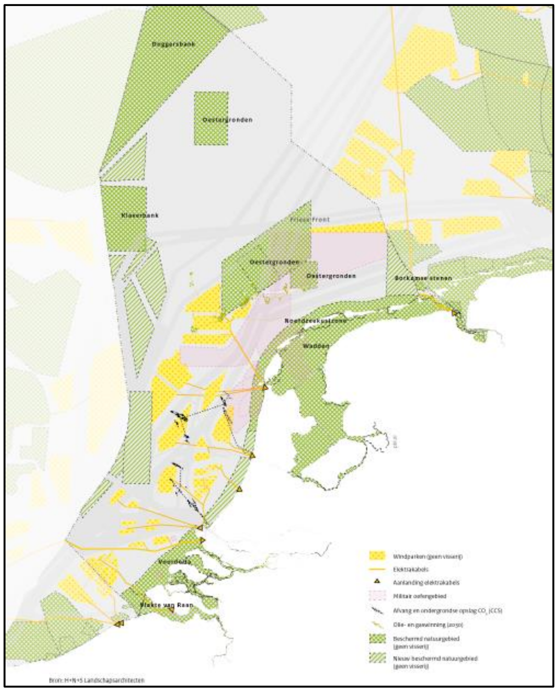


Figure 43: Possible arrangement of offshore wind parks in the North Sea
Source: Matthijsen et al. (2018

Netherlands. Solar panels are only employed on location where it does not compete with other land use (for example agriculture). This makes the contribution of solar pv to the energy transition only limited by mostly solar panels on rooftops. However also the solar panels on individual households has not experienced any significant development due to the passiveness of the Dutch society.

Energy storage

Because renewables have penetrated over 30% in the generation of electricity management addition measures are needed to keep the grid stable. Due to the absence of a better international cooperation and interconnectivity and no further DSM developments energy storage is the most important contributor to the stability of the electricity grid. As the generation of renewables is mostly done on the central part of the electricity grid, the storage of energy is also done on the central part of the grid. Interviewer 1 points out that on a centrally oriented electricity grid hydrogen is a much promising way of storing energy and this will make hydrogen the most important energy storage method. The storage of electricity in hydrogen will be done by large units of electrolyzes. These units split water into hydrogen gas and oxygen, called Power to Gas. The most suitable location for these electrolyzes is near the shore where the electricity cables, connecting the wind turbine farms on the North Sea, come to shore. This way the distance between the place of generation and the storage of energy is the closest to each other and transport loss is reduced to the minimum. In figure 43 suitable locations would be on places where the triangles are but these locations can differ as the places where the electricity cables come to shore can differ to. On moments where the generation of wind energy is overflowing the grid the abundant electricity will be stored in hydrogen energy and when electricity is scarce the hydrogen is used to generate electricity. Interviewer 1 points out that changing the combustor in gas turbines makes gas turbines suited for the generation of electricity with hydrogen. As the electricity grid in the Netherlands is currently relying heavily on gas, opportunities to transform gas turbines into hydrogen turbines are abundant. Depending on different factors it can occur that new, more efficient hydrogen generators are build but also that the current gas turbines are transformed to hydrogen turbines.

Demand side management

In the current situation DSM was already present by EE measures and TOU tariffs. In this scenario these measures continue to be taken which increases the EE of buildings. Also TOU tariffs are still present to decrease peak demand moments and to ease the grid. No additional measures are however taken compared to the current situation. The only passively involved society is not eager to change behavior by DR and fully flexible electricity prices. Hence the influence of DSM as a balancing method has not developed any further and of the three possible balancing methods has the least influence on the electricity grid.

PEV

The electric vehicle will penetrate more into the electricity market but will not be the dominant type of automobiles. 20% of the automobiles will be an electric vehicle of which almost all vehicles are PEV. Because hydrogen is generated on a large scale, also the hydrogen powered vehicle will be present on the roads and is one of the reasons why the electric vehicle has not penetrated further. Due to the relative slow speed of the transition in this scenario still the majority of automobiles will be powered by petrol, which is the other explanations for the relative low penetration of the electric vehicle. The costs of the conventional automobiles are still below the costs of the electric vehicle in this scenario.

The relative low penetration of the electric vehicle also has consequences for the development of the electric vehicle charging network. Due to the low penetration of the electric vehicle the change in the charging network is limited. The current charging network is only intensified adding more charging poles in residential areas and increasing the fast charging network on strategical places.

The electric vehicle is not used as a storing device which communicates with the grid, hence V2G is not applied in this scenario. This makes the electric vehicle an extra burden for the electricity grid. Flexible charging is introduced, due to the potential burden electric vehicles can be for the electricity grid. Flexible charging gives electricity suppliers the possibility to disconnect charging poles from the network on moments the demand becomes too high (Ministerie van Economische Zaken, 2016b). The uncertainty concerning the charging, the passive Dutch society and the relative high price of the electric vehicles has slowed down the penetration of the electric vehicle in this scenario.

Grid investments

The classical divide between a central generation of electricity and a decentral consumption of electricity has stayed in place in the scenario. A shift from an almost fully conventional generation of electricity towards a combination of conventional energy sources and renewables is a change and does have an influence on the electricity grid. The intermittency of the offshore wind parks has to be dealt with. As Albadi & El-Saadany (2010) already mentioned and interviewer 1 points out, a larger expanded electricity grid will offer more stability when intermittent renewables penetrate further. For the central electricity grid in the Netherlands it is not possible to expand much further and due to the relatively small size of the Netherlands this intermittency can cause problems. A better interconnectivity is used as a solution to deal with intermittency problems, however due to the lack of international agreement on rules and regulations interconnectivity benefits are not optimized. Hence interconnectivity only contributes moderately to the stability of the electricity grid. The investments in the interconnectivity are made on the" koppelnet", the part of the electricity grid in the Netherlands, which is already connected to other grids of neighboring countries. These investments can be on new connections or upgrading the current connections. Matthijssen et al. (2018) points out that this international collaboration is of vital importance for a fast energy transition and because this collaboration is not optimized in this scenario, the penetration of renewables is slowed down.

National grid investments are mainly aimed on connecting the new wind parks on the North Sea to the national grid. The current wind parks on sea Egmond aan Zee (108 MW), Prinses Amalia (120MW), Luchterduinen (129 MW) and Gemini Offshore Windpark (600MW) are suitable for connecting to the transportnet whereas the latter one is near the limits of the transportnet and can also be connected to the koppelnet (Matthijssen et al., 2018). This means investments of smaller offshore wind parks needs investments on new connection on the transportnet and bigger offshore wind parks demand investments on new connections on the koppelnet. An example of connecting the wind parks to the current electricity grid is given in figure 43 where the yellow lines resemble the connection of the wind parks to the shore of the electricity grid in the Netherlands.

On the already existing part of the central electricity grid no major investments are needed, because the electricity demand has only grown 5TWh this scenario. Also the decentral grid does not need major investments because electricity is still generated centrally and the total annual electricity demand has only grown with 5TWh.

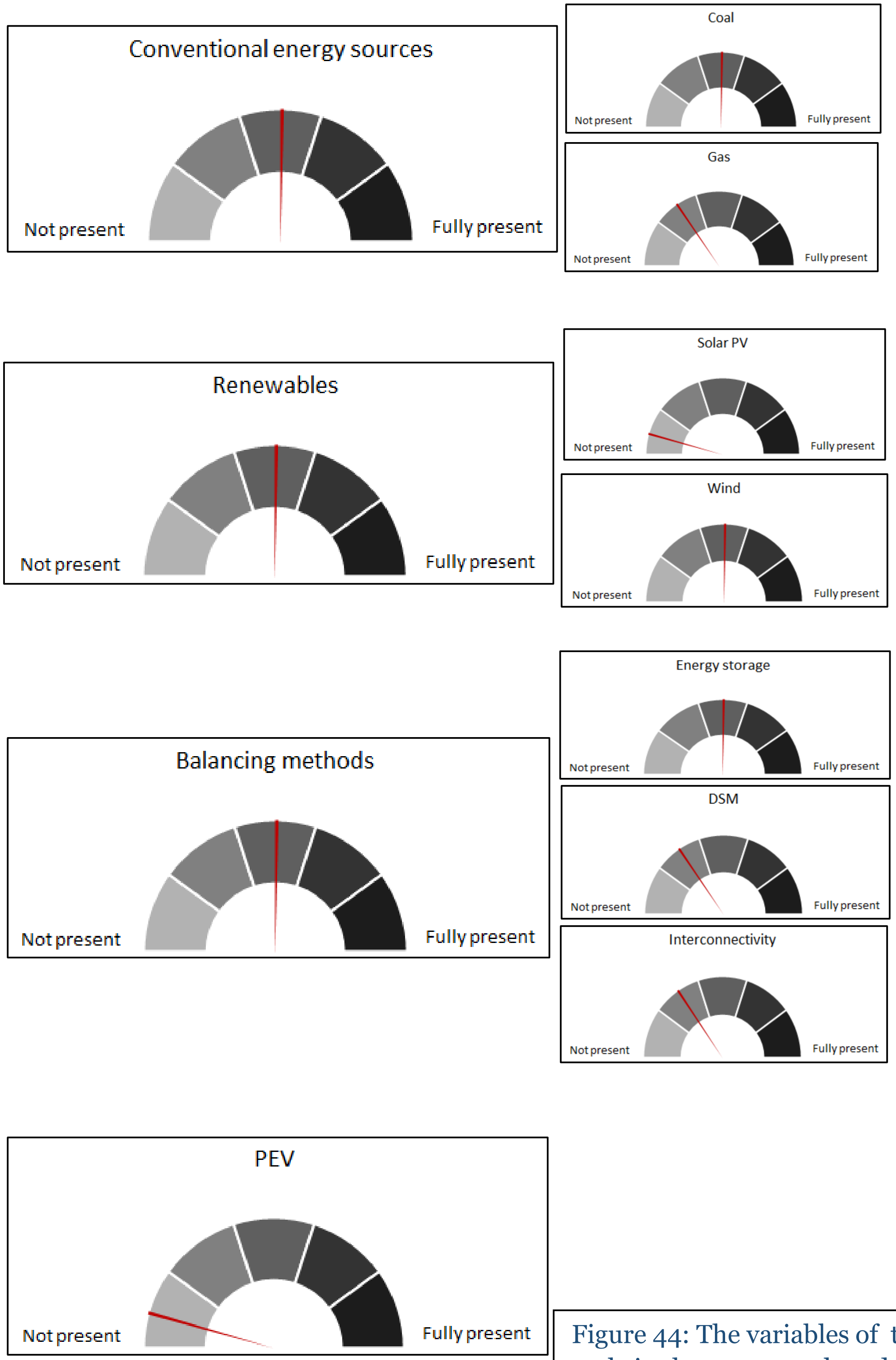


Figure 44: The variables of the scale in the conceptual model in the scenario; Empowering the

4.4.2 Scenario 2: Strong European Grid

Context of change

International collaboration has intensified and international agreement on law and legislation has intensified. Together all neighboring countries of the Netherlands share their responsibility of empowering the energy transition. For the Netherlands this means the Dutch national government together with the TenneT has taken their responsibility in the shared ambitions. Due to the international focus the grid is highly centralized. Large renewable projects are mainly focused on centralized locations where grids of the different countries are connected to each other. Due to international collaboration, smaller national grids are connected to each other creating one "international super grid". The large size of this international super grid is much more resilient to the intermittency of renewables, hence enabling a faster penetration of renewables. The fast penetration of renewables leave little space for conventional energy generators and CCS is considered as undesired. Due to the high penetration of renewables, energy storage becomes an important aspect. To keep transport losses minimized energy storage will be done as much as possible near the source of renewables. Because the national governments have taken full control of the energy transition involvement of local and provincial governments is only limited. Also the Dutch society is only passively involved at the energy transition.

The international agreement on a fast energy transition is empowered by an extremely high price of CO_2 emission rights near the top price of figure 39. Also international agreements on taxation of petrol has increased the price of petrol significantly. Altogether the international collaboration has pushed the speed up the energy transition to its limits. However due to the passivity of the Dutch society the electrification is not optimized. Conventional cars are replaced by cars which drive on renewable energy sources (electric, hydrogen) but due to the passivity of the Dutch society petrol cars still play an important role. Also the replacement of gas fired heating by heat pumps has only progressed on an average pace. Altogether the total electricity demand has risen significantly from 115 TWh to 135 TWh.

The variables

Conventional energy sources

Strict environmental policies have pushed the penetration of renewables, hence the contribution of conventional energy sources have decreased rapidly. Especially the price of CO_2 emission price has increased rapidly which made the generation of electricity with conventional energy sources more expensive than renewables. CCS is not considered as a sustainable long term solution. Only 20% of the total electricity is generated by conventional energy sources, hence conventional energy sources only play a minor role. The goal of the Netherlands to completely outsource coal fired power plants have been executed. Gas power plants are the source of conventional energy sources which still contribute to the electricity system in the Netherlands.

Renewables

Renewables are the main source of electricity generation (80%) and the main source of renewable generation are offshore wind turbine parks. Due to more efficient wind turbine technologies and international agreements concerning policies and legislation the penetration of wind energy went rapidly. Due to the resistance of onshore wind turbines the Dutch national government has chosen to focus on large offshore wind turbine parks connected to the central electricity grid. Almost the whole Dutch territory of the North Sea is used for the energy transition. Combinations with other land uses on the North Sea is established which optimizes the revenues of electricity generation on the North Sea. Figure 45 from Matthijssen et al. (2018) shows a possible arrangement of the North Sea for this scenario. This scenario described by Matthijssen et al. (2018) is the scenario where the penetration of wind energy on the North Sea goes the fastest, which is called “Samen Duurzaam”. Not only the possible location near the shore are used also location further away from the shore are used as wind park locations. An example of this location is near the Doggersbank, in the North of the Dutch territorial water. The locations near the Doggersbank is used because firstly all the available space is needed and secondly because the Doggersbank is a strategical location for international collaboration (Matthijssen et al., 2018). The wind parks further away from the shore will grow especially large (over 500MW) and are also important in the international collaboration. The koppelnet is the most important part of the grid to accommodate these wind turbine parks. Interviewer 2 points out that as renewables penetrate further it is increasingly important that different types of renewables are used. Using only one type of renewables will increase the peak generation moments and also will cause an extremely low generation on moments no wind is present. The intensity of peak and off-time generation moments will be reduced by combining both solar pv and wind energy. Interviewer 2 also points out that floating solar parks can be a valuable addition to wind turbines on sea. These floating solar parks can be stationed between the off shore wind turbines and will be part of the generation of the offshore wind parks. However, the offshore solar parks will only have a minor contribution due to the relatively large space it needs.

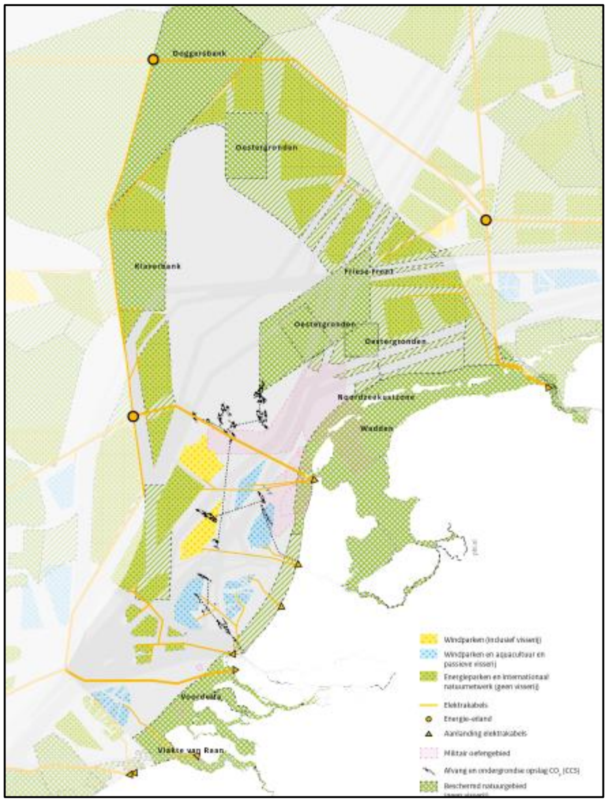


Figure 45: Possible arrangements of offshore wind parks in the North Sea Source: Matthijsen et al. (2018

Energy storage

Due to the large penetration of renewables balancing methods become more important as well. Energy storage will play an important role in keeping the electricity grid stable. The North Sea Power Hub (NSPH) will play an important role in the storage of electricity (see figure 46). An artificial island in the North Sea is needed to create this hub and offer space for the different benefits it can offer. The ideal spot for an artificial island on the North Sea is an area where the sea is relatively shallow. TenneT (2017) has pointed out the Doggersbank as an ideal spot due to its shallowness and expects the island to be roughly 6 km2. This area is located in the North of the territorial waters of the Netherlands (see figure 45). Many of the surrounding wind turbine parks will be connected to the NSPH. On the NSPH electrolysis will be used to create hydrogen gas from abundant intermittent wind energy (Power-to-Gas). Converting electricity into hydrogen will not only make the electricity grid more stable on moments renewables generate more electricity than is needed, but will also create a sustainable energy source which is fully controllable. The hydrogen which is created can be used on moments where electricity demand is outweighing the electricity generation. A big advantage of storing energy into hydrogen is that during the storing period hydrogen will not lose any of its energy. This makes hydrogen an ideal storing method for long term storing. The transportation of hydrogen can be done by already existing gas pipelines of the GasUnie on

the North Sea, which are currently used to transport conventional gas between the different North Sea countries. The hydrogen is used in former gas turbines which can generate electricity from hydrogen with an adjustment in the combustion engine as pointed out by interviewer 1. Because the hydrogen will be used in former gas power plants the grid will also stay highly centralized.

Figure 46: North Sea Power Hub *Source: www.TenneT.nl*

<u>DSM</u>

As in the previous scenario DSM has not developed any further. EE measures and TOU tariffs are still the only DSM measures used. The TOU measures are used to make sure the daily peaks are managed. Just like in the previous scenario DSM is not developed any further due to the passivity of the Dutch society.

<u>PEV</u>

Of the total automobile market, the electric vehicle has a share of 50%. The total amount of vehicles has stayed roughly the same which means that roughly 4 million electric vehicles are present in the Netherlands. However due to the absence of demand response and flexible pricing, V2G cannot be applied. The electric vehicle does not contribute to the stability of the grid but is an extra burden for the electricity grid due to the extra demand. To cope with the possible high demand flexible charging is introduced. This gives the grid operators the possibility to temporarily disconnected the PEV from the electricity grid when the demand becomes too high. Electric vehicles are charged via the current charging infrastructure. However due to the penetration of the electric vehicle the current charging infrastructure has to be expanded enormously. The charging infrastructure will become highly visible in the residential areas where the density of the population is the highest. Also the fast charging network has expanded significantly which means virtually every gas station will have a fast charging station.

Grid investments

The expansion of wind turbine parks in the North Sea demands investments on new grid connection. Because the wind turbine parks will be >500 MW investments in new infrastructure on the koppelnet is needed. These wind turbine parks will be connected to the NSPH or other Power Hubs on territorial waters of neighboring countries (see figure 47). Besides the conversion of electricity into hydrogen, the NSPH will also function as a central place where international electricity trading takes place. All countries bordering the North Sea will be connected to this hub. The NSPH is the international connection which makes all the electricity grids of the surrounding countries function as one larger grid. This interconnectivity is needed to deal with the intermittency of the renewables, which has penetrated to 80%. International agreement legislation and regulations concerning electricity trading has been established which has optimized the interconnectivity and electricity trading. Interconnectivity is the preferred way of dealing with intermittency of renewables, above energy storage and DSM. Figure 47 shows the concept of the NSPH, where Belgium, the Netherlands, Germany, Denmark, Norway and the United Kingdom function as one larger grid due to the interconnectivity via the NSPH. Due to the large distance between the NSPH and the Netherlands the commonly used alternating current cannot be used. Establishing an alternating current connection between the NSPH and the shore of the Netherlands will result in a transport loss of 60% (TenneT, 2017). Direct current electricity lines will increase the efficiency to almost 100% and will be used to connect the NSPH to the mainland of the Netherlands. The capacity of the connection will match the koppelnet and can be considered as an expansion of the part of this part of the grid. Onshore a converter is needed which converts the direct current to alternating current to make it suitable for the electricity grid in the Netherlands. Because the annual electricity demand has risen from 115 TWh to 135 TWh also some small investments are needed on the electricity grid as a whole. These investments concern upgrading the capacity off the electricity grid on places where the current electricity grid cannot cope with the peak load moments on the central and decentral grid.

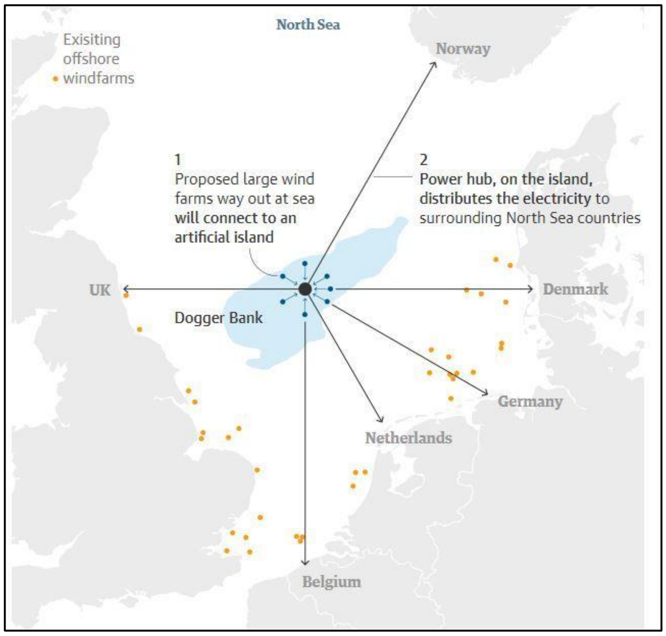


Figure 47: Possible location of the North Sea Power Hub
Source: www.digitaljournal.com

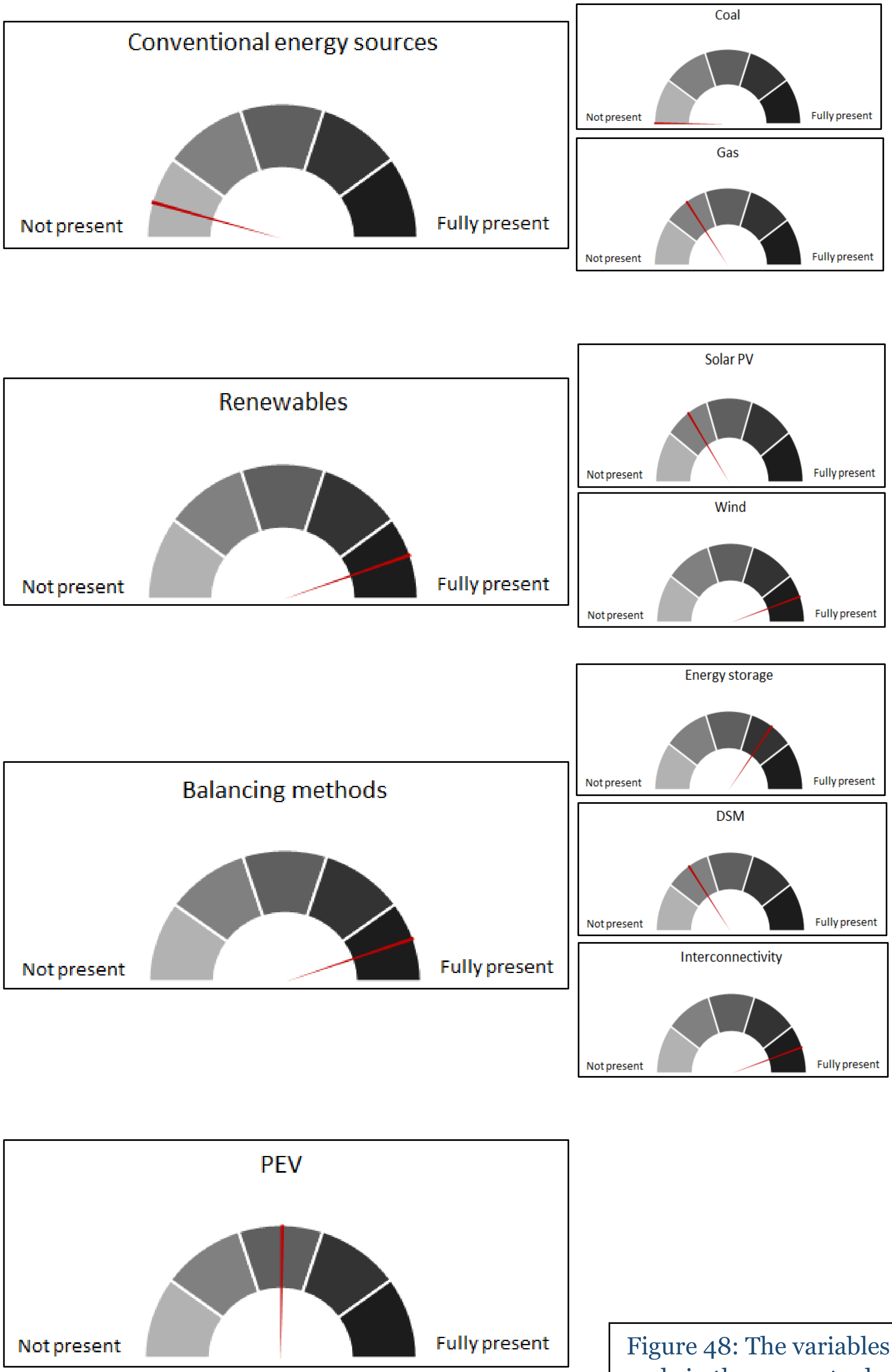


Figure 48: The variables of the scale in the conceptual model in the scenario; Strong European Grid

4.4.3 Scenario 3: Local heroes

Context of change

The national government has assigned the provincial and local governments to take responsibility in the energy transition. The Dutch society is feels the urge of a fast energy transition and is actively involved in the transition. Together with the regional grid operators and companies, the Dutch society takes a leading role in the energy transition. The local and provincial governments have taken the role of facilitator mainly mediating and seeking solutions when different interests are at stake. Due to the support of the society decentral developments especially in urban areas have gone rapidly. To avoid transport losses and maximize efficiency storage of electricity is also done on a local level. The high involvement of the Dutch society has triggered a fast development of DSM. Together with energy storage they manage the stability of the grid. Due to the high penetration and storage of renewables locally, semi-autonomous neighborhoods have appeared and the consumer has become a prosumer. In the rural areas, where there is space for larger projects the developments are slowed down. Visual intrusion and competing with other types of land use are the main arguments off the resistance. Due to the high focus on local developments, central developments has halted. The energy transition is further triggered by a moderate increase in the price of CO_2 emission rights and a moderate increase on the price of petrol, giving not only a moral trigger but also an economic trigger. The overall electricity demand has increased moderately to 135 TWh due to increase of EV's and an increase in the use of heat pumps.

The variables

Conventional energy sources

The generation of electricity is divided evenly over conventional energy sources and renewables. CCS is not considered as a solution in this scenario because CCS has to be applied on the central grid. The goal of the Dutch government to completely phasing-out the coal fired power plants has been executed. The remaining 50% of the total electricity is generated by gas power plants. The generation of electricity via gas power plants is roughly the same as in the current situation. Current efficient gas power plants will still be active in this scenario and older, less efficient power plants will be replaced by new power plants.

Renewables

Local initiatives have grown enormously in this scenario. Inhabitants of neighborhoods have started to cooperate which each other on a large scale. The covering of rooftops with solar panels has speeded up rapidly and due to this the main generation of renewables is taking place on the "lokale distributienet". Electricity generated on a local scale is attempted to consume in the same neighborhoods, which greatly reduces transportation loss. The penetration of wind turbine generation has halted. Visual intrusion is an argument which has remained, hence wind energy contributes only little to the total electricity generation. Also the fast exploitation of large solar parks in rural areas has stumbled on resistance. In general, agricultural and nature land use are preferred over renewable land use.

To enhance the fast penetration of renewables new solar technologies are needed. Heijmans (2015) points out several promising solar technologies which can enhance the generation of solar pv electricity. Firstly, the solar road, consisting of solar panels which can endure the pressure of automobiles driving over it. Covering roads with solar panels improves the possible surface which can be covered with solar panels, hence opens up the possibility of a deeper penetration of solar pv. Figure 49 shows a concept of how a solar road can look like. If the weight of vehicles driving over it proves to be challenging it is also possible to only cover bicycle lanes with solar panels. There are already pilot projects of solar cycling roads in the Netherlands as shown in figure 50. This will be especially effective in the Netherlands due to the fast extended cycling infrastructure. The current road infrastructure in the Netherlands has twice the surface of the all rooftops combined, which shows the enormous potential (TNO, 2010).

The second promising development concerning Heijmans (2015) are the transparent solar windows. These solar panels guide the light towards the edge of the panel where it is converted into electricity. Applicability on a local scale can be found in changing normal windows of building into solar panel windows which again increases the surface on which solar energy can be applied.

The last technology which can increase the generation of solar energy is thin film solar. These solar panels are extremely thin and flexible which makes curved objects also suitable for solar energy generation.

Altogether in this scenario the image of the neighborhoods will change drastically. Virtually every surface aimed to the right direction (not North) can be used to generate solar energy. How every neighborhood will exactly look like will also depend on the inhabitants of the neighborhood. What is sure is that a large part of the residential area will be covered with solar panels and is supported by local inhabitants which are involved in the planning and realization of these solar neighborhoods.

Figure 49: SolaRoad Source: www.heijmans.nl

Figure 50: Solar cycling road Source: www.heijmans.nl

Energy storage

The shift from a central oriented electricity grid to a mix of central/decentral oriented electricity grid also has its influence on the storage of electricity. Renewables are mostly generated on the lokale distributienet and to avoid transportation losses electricity is also stored on the "lokale distributienet". Because the generation of electricity on the central grid are conventional energy sources which can be adapted to the demand no storage on the central grid is needed. V2G will be used as the main storage method which will take place on the "lokale distributienet". Due to the generation and storage of electricity on the "lokale distributienet" energy efficient neighborhoods can become semi- autonomous, needing only little support from the central grid.

DSM

DSM is the most important balancing method to keep the grid stable in this scenario. Energy efficiency measures, already present in the current situation, are intensified. The real game changer in this scenario are the fully flexible electricity prices, called demand response in the theoretical framework. Because most of the renewables are generated by solar energy it is needed that electricity is used on moments it is generated. As shown in the theoretical framework, solar pv has a quiet predictable peak and off time generation of electricity. Peak moments are usually between 11:00 AM and 03:00 PM and electricity is ought the be used mostly during this period. Fully flexible electricity prices will give incentives for individuals to charge their PEV during the moments electricity is abundant and prices are low, during the peak moments. The "fuel" for the PEV will be cheaper these moments and will be the incentive to charge

your vehicle and keep the grid stable. The economic incentive in combination with the actively involved Dutch society makes DR a very effective balancing method where demand is adjusted to supply.
Also smart household machines will take part in stabilizing the electricity grid. These smart household machines are connected to a smart meter which communicates with the grid and monitors the current and near future electricity prices. Smart household machines can be programmed to automatically turn on when the electricity prices are the lowest and the most profitable for the consumer. Due to the amount of PEV's and the possibility that many PEV's are plugged in at the same time IT solutions managing the electricity flows are needed. Interviewer 1 and 2 point out that demand response is the aspect which turns the conventional grid into a smart grid. A grid which predicts near future electricity generation and tries to change the behavior of consumers in order to fit supply and demand.

PEV

Approximately 50% of the total automobiles in the Netherlands are electric, which means roughly 4 million electric vehicles are present. The large share of PEV's also demands a change in the (urban) environment. Because renewables are mostly generated on the "lokale distributienet", the PEV is also charged on this part of the grid. To accommodate the 4 million PEV's the charging infrastructure is developed rapidly and will have a significant impact on the physical environment. Especially in urban areas the charging infrastructure will become visible and has a large impact on the physical environment. The PEV however will not only be an extra burden for the smart grid but will also function as V2G. The combination of local generation of electricity, V2G, and fully flexible electricity prices will together manage the stability of the electricity grid. Especially neighborhoods which are energy efficient become semi-autonomous, only needing a limited aid of the centrally generated electricity.

Grid investments

The focus in this scenario lies on the locale distributienet concerning the renewables and on the transportnet for the conventional energy sources. Because the current situation almost fully generates electricity on the central electricity grid this scenario will mean a decrease in generation of the central electricity grid. Consequently, this will also mean that little investments are needed on the central electricity grid. On the lokale distributienet generation of solar electricity takes place. This will mean an extra burden for the locale distributienet and extra investments are needed to prevent curtailment of solar energy. These investments are mostly aimed at upgrading the capacity of the "lokale distributienet Also the PEV will demand extra electricity which further emphasizes the need of upgrading this part of the grid. The other large investment which is needed on the "lokale distributienet" is the expansion of the charging infrastructure network. This is needed to accommodate the 4 million PEV's present in this scenario. Although the "lokale distributienet" is upgraded this part of the grid is not suited for large electricity generation and transport in large quantities. Upgrading is limited because the voltage of the lokale distributienet is suited for the use of individual households. Renewables have been pushed to the limits in the urban areas but the urban areas are not able to fully accommodate the energy transition. Intensifying the interconnectivity with neighboring countries is not needed. V2G, flexible electricity prices, and smart household machines matches supply and demand in most cases and when these measures are not sufficient the decentral grid will be supported by conventional energy sources on the central part of the grid. The most challenging part of this scenario is the prediction of the near future weather forecasts and related to this the electricity generation. Weather forecasts has to be incorporated in the price of electricity to effectively manage supply and demand. When weather forecasts are not accurate this can cause a high demand and moments generation of electricity is low.

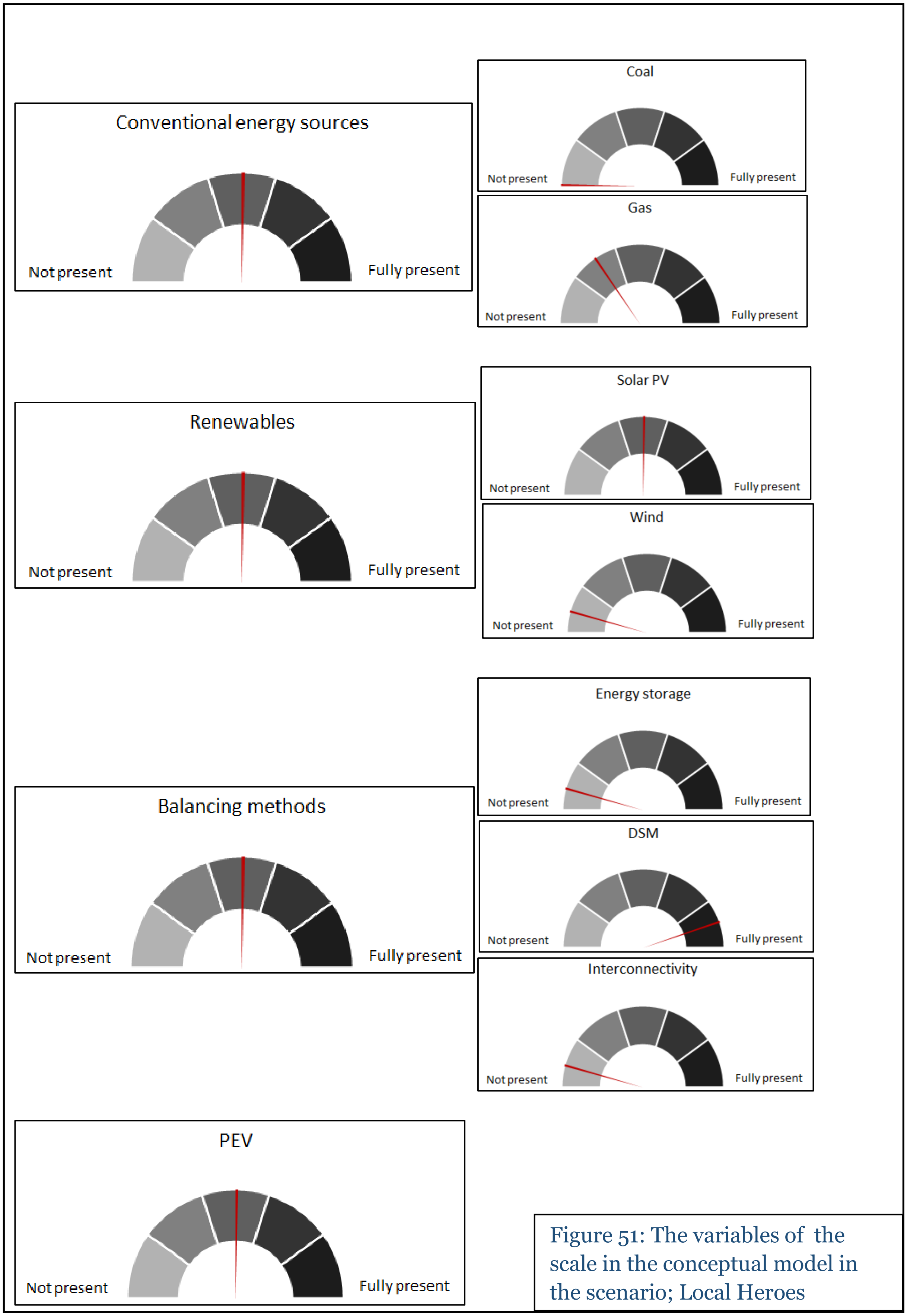


Figure 51: The variables of the scale in the conceptual model in the scenario; Local Heroes

4.4.4 Scenario 4: The smartest of Grids

Context of change

Just as the previous scenarios the Dutch national government has assigned the local and provincial governments to take responsibility for the energy transition. The Dutch society regards sustainability as one of the most important subjects. Together with companies the Dutch society empowers the energy transition. On the local as well as on the regional level, a large quantity of projects have been realized. The local and provincial governments have taken mostly a facilitating role but have also taken a leading role on projects with resistance. Together the society, governments, grid operators, and companies are aiming for an "all-electric society" in 2050. This has not only caused a fast transition on the electricity grid but also a fast transition on the energy system as a whole. Most of the conventional vehicles have been replaced by electric vehicles and most conventional heating has been replaced by heat pumps. All together this has caused a large increase in electricity demand to annually 150 TWh.

Storage of electricity is of vital importance to keep the grid balanced. This is mostly done on the part of the grid where most electricity is generated, the "regionale distributienet". Storage of energy is stimulated by a well-developed DSM. Energy storage together with DSM however is not enough to keep the grid stable in this scenario. Due to the high penetration of renewables also the capacity of interconnectivity is increased. This is however considered as the last option after DSM and energy storage is not sufficient. This grid is the most complex of all scenarios due to the high penetration and amount of renewable electricity generating units, energy storage, DSM and interconnectivity. This high complexity demands the smartest grid of all scenarios.

The variables

Conventional energy sources

Coal fired power plants and considered as the most undesired source of conventional energy and the goal of the Dutch government to completely outsource coal has been executed. The only conventional energy source which is used to generated electricity is gas. The gas generators are responsible for roughly 20% of the total generated electricity. The remaining gas generators will operate on the transportnet. Due to high CO_2 emission pricing only the most efficient gas generators will play a role in this scenario.

Renewables

The generation of renewable energy will take place on both the locale distriubtienet and the regional distributienet. On the locale distributienet the generation of renewables is done with solar panels on rooftops. This generation of renewables is however mostly done on the regional distributiennet. As interviewer 2 points out, to achieve a high penetration of intermittent renewable energy the focus shouldn't be on the local distributienet. This is because the capacity of the local distributienet is not fit for transporting a large amount of electricity even if it is upgraded. As intermittent renewable energy penetrated further this problem will become more severe. To achieve a high penetration of renewables on a decentral level it is desired to have the main generation of renewables on the regionale distributienet and the generation of electricity on the "lokale distributienet" as support. The main generation of electricity is done via clusters of solar parks in combination with wind turbines on land. Clustering wind and solar energy is important because in general this will decrease the intensity of the intermittency and peak and off peak moments as pointed out by interviewer 2. To enable a large share of solar pv and wind turbine clusters two constraints have been overcome. Firstly, the resistance of wind turbines on land has to drop. Secondly, the current problem with solar panels in the rural areas is that it competes with other land use (nature, agriculture). Interviewer 2 points out that currently most municipalities prefer wind energy above solar energy due to this reason. Agricultural land is too valuable for municipalities to cover it with solar panels. Interviewer 2 also points out that current pilot projects experiment with fully transparent solar panels in rural areas. Fully transparent solar panels assure that agriculture as well as renewable generation can take place in the same space. The agricultural revenues will decrease between 10% – 15 % but because the solar panels can generate electricity two-sided the revenue of these solar panels will increase. Furthermore, interviewer 2 points out that this development can empower large scale employment of solar panels in rural areas. Also east-west oriented highways are interesting for large scale solar panel generation. Highways are interesting places to generate solar energy due to the ownership of the adjacent land by Rijkswaterstaat. Currently the adjacent land has no specific function, solar panels can add value to these areas. The so called "zonneroute" is a concept which is being researched by Rijkswaterstaat, the Dutch governmental organization which is responsible for the Dutch highways. The aim is to cover the sides of the 43 kilometer long highway. Figure 52 is a visual representation of the "zonneroute". Because the regional electricity grid also has its limitations, a certain amount of geographical dispersion is needed to avoid overloading on certain parts of the regionale distributienet and to minimize transport losses. Clusters of solar pv and wind turbines will be present throughout the Netherlands.

Figure 52: Zonneroute *Source: www.dvhn.nl*

Energy storage

Energy storage is an important aspect of storing energy in this scenario. Due to the high penetration of the EV and fully flexible energy pricing a large amount of electricity can be stored in the EV. Interviewer 1 points out that the self-driving vehicle can have significant impact on the spatial environment, which has exactly taken place in this scenario. This in combination with the sharing economy, which is also pointed out by interviewer 1, has determined the main developments in the automobile industry. Due to the sharing economy the EV's are not stationed in the neighborhoods anymore but have shifted to central locations on the edges of urban areas where large charging stations are connected to the "regionale distributienet". For every trip of the self-driving EV, point of departure is the central charging station. The charging stations are also considered as large batteries where V2G is applied. Together all the self-driving EV's form a large battery on the edges of urban areas and offer a large amount of storing capacity. V2G, and a self-driving vehicle combined maximizes the potential of V2G and the storage capacity of the self-driving vehicle and can be more effectively used compared to the PEV. Transportation costs are minimized due to the high generation of electricity on the "regionale distributienet" and also the presence of storing on this part of the grid.

DSM

Together with the energy storage, DSM will play the main role in stabilizing the electricity grid in the Netherlands. Firstly, energy efficiency measures will play an important role. The energy intensity has increased significantly in this scenario because isolation of buildings has taken place on a large scale.

However due to the mass application of the PEV and the heat pump the total electricity demand has grown. Time of Use tariffs have been replaced by the demand response incentive of fully flexible electricity prices. This incentive is needed to decrease peak load moments and to give incentives for V2G. The core of balancing the electricity grid consists of fully flexible electricity pricing combined with V2G. This combination again is optimized by the self-driving vehicle which will be automatically connected to the grid when the prices are the lowest. Besides the EV which response on fully flexible electricity pricing also smart household machines will have influence on the stability of the electricity grid. Household machines are turned on when electricity prices are the lowest, hence electricity is abundant. All the DSM measures are supported by the Dutch society who are actively involved at the energy transition. Due to the high generation of renewables on the decentral grid, this scenario contains the most units which generate electricity. On the "lokale distributienet" on many rooftops and on the "regionale distributienet" with many clusters of solar pv/ wind turbines and other applications as the zonneroute. The large amount of generation units and high penetration of renewables demands the smartest grid of all scenarios. Storing electricity, predicting weather forecasts and effects on electricity generation, the near future electricity prices should all be in balance to establish a stable electricity grid.

PEV

With 80% the PEV has penetrated the furthest in this scenario. The penetration of the EV is caused by rapid developments in the automobile industry. Induction charging has penetrated the market and has replaced the current PEV. Induction charging is a method which uses electromagnetic fields to charge electric vehicles without a wired connection to the electricity grid as shown in figure 53. Induction charging is method which suits the development of the self-driving vehicle because no human action is needed to plug in the EV on the electricity grid. When a car is fully charged it can be automatically replaced by another car in the central charging stations hence optimizing the storage capacity of the EV. Another advantage of induction charging is that vehicles can be charged during the trip. Induction panels can be incorporated in the road. When the EV drives over these panels they can be charged during the trip as shown in figure 54. This not only offers a larger storing capacity with the same amount of EV's but also increases the range of the EV. The development towards a sharing economy has decreased the total automobiles in the Netherlands from roughly 8 million to 6 million because cars are more efficiently used. The charging infrastructure is also changed from individual charging poles towards central induction charging. This changes the physical environment of neighborhoods where only a small amount of non-induction vehicles is parked and space for parking is reduced greatly. The charging poles will disappear almost completely from the physical environment. Interviewer 1 points out that expanding the charging pole infrastructure is the most expensive aspects of empowering the electric vehicle. Because this obstacle is removed in this scenario the EV has the largest share of the total automobiles of all scenarios. Induction charging does not have to be constructed for every individual vehicle, hence greatly reduces the investments in the charging infrastructure. Due to the self-driving vehicle and the automatic charging the vehicle industry works mostly autonomous with on little interference of humans.

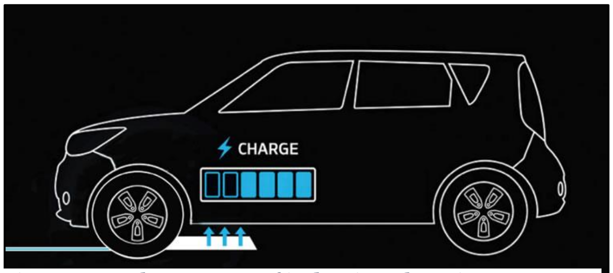


Figure 53: The concept of induction charging
Source: www.fluxenergie.nl

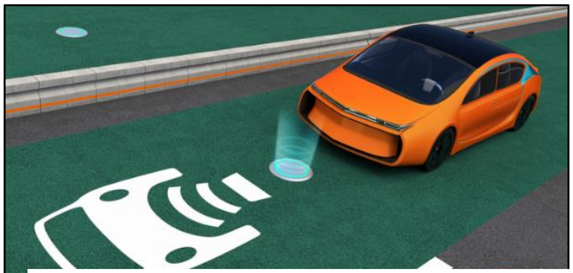


Figure 54: Induction charging while driving
Source:www.chargepoint.com

Grid investments

A spectacular shift from an almost fully centrally oriented electricity grid towards a mostly decentralized electricity grid has taken place. This shift also demands heavy investments on the electricity grid. Both the locale and regionale distributienet are transformed from a part of the electricity grid which mainly distributes electricity towards a part of the grid which transports as well as accommodates generation of electricity. The additional generation demands extra investments on these parts of the electricity grid. On the locale distributienet these investments are mainly focused on increasing the capacity because the generation of electricity mainly takes place on rooftops. These buildings are often already connected to the electricity grid but will increase the amount of electricity the locale distributienet has to deal with. On top of this is the large increase of EV's and heat pumps to achieve an all-electric society. On the regional distributienet the capacity of the electricity grid has to be increased. This is due to the clusters of solar panels and wind turbines which generates electricity on the regionale distributienet and other regional developments like the zonneroute. Besides increasing the capacity on the regional distributienet also new connection are needed. These connections are needed firstly to connect the clusters of solar farms and wind turbines on the electricity grid and secondly to connect the central charging of self-driving electric vehicles to the grid. Also investments are needed to connect induction panels in the road to the electricity grid. On the central grid investments are needed due to the high penetration of renewables. These investments are focused on a better interconnectivity with neighboring countries. A better international connectivity is needed to accommodate the high penetration of renewables but is only preferred if DSM and Energy Storage cannot keep the grid stable. However especially for a small country as the Netherlands, which will be heavily influenced by certain weather system a better interconnectivity is of vital importance for a high penetration of renewables. Due to the high penetration of renewables on both the lokale and regionale distributienet and the need of a better interconnectivity with neighboring countries the electricity flow has changed completely in this scenario. On different moments electricity can flow to different directions. When electricity is imported a conventional flow from central to decentral but there can also be an abundance of electricity on the lokale and regionale distributienet. All directions of electricity flow are possible in this scenario making it by far the most complex.

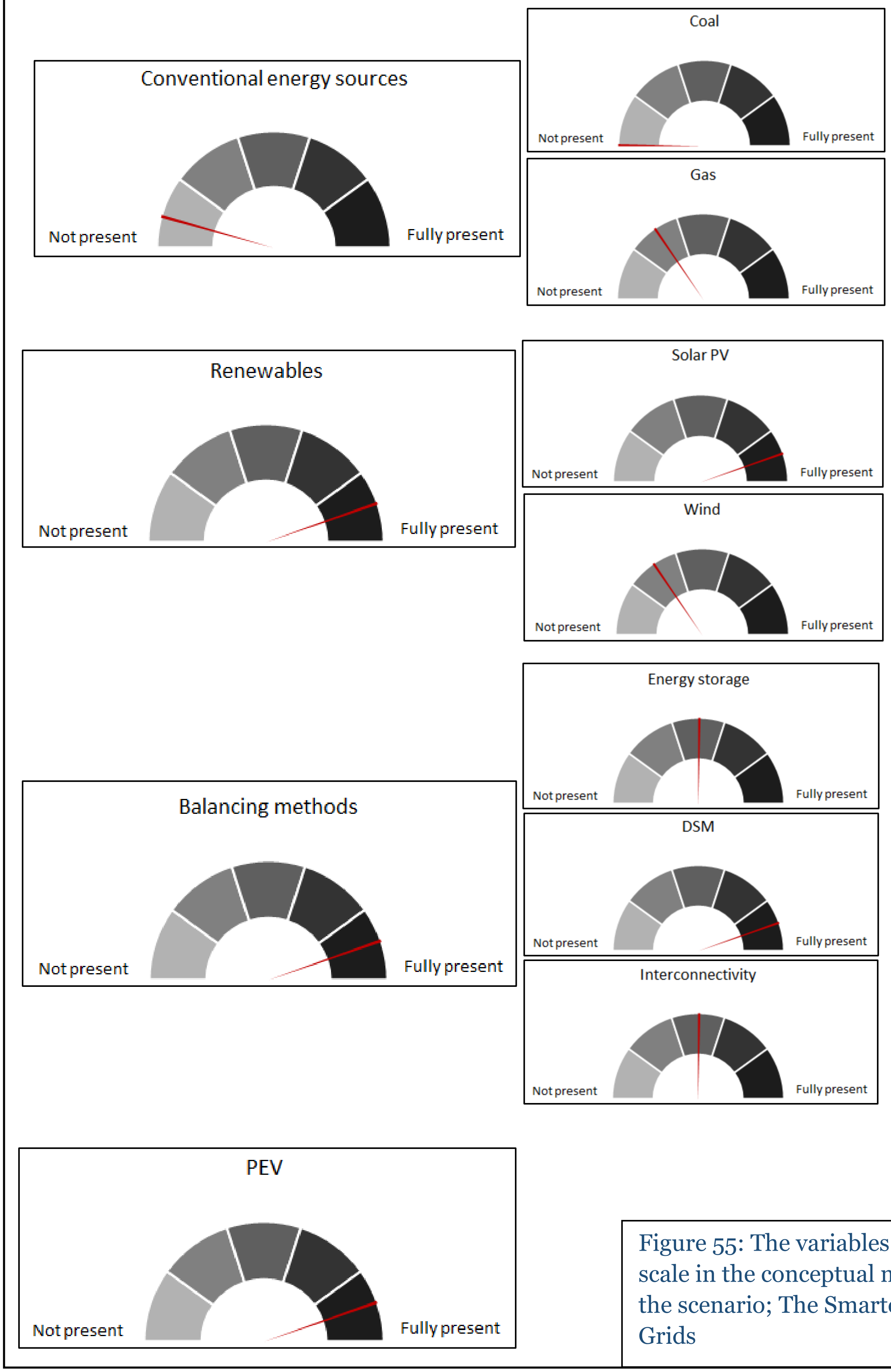


Figure 55: The variables of the scale in the conceptual model in the scenario; The Smartest of Grids

5 Results

The next chapter is aimed at giving insights in the uncertainty which surrounds the electricity grid in the Netherlands in 2035-2040 and executes step 4 of the conceptual model (see figure 56). This chapter consists of four section in which the variables in the four scenarios are compared. By comparing the variables in the scenarios a potential masterplan and potential contingency plans can be identified.
The first section is dedicated to identifying a masterplan. The developments identified for a masterplan appear in all four scenarios and are the most robust. The second section is will elaborate on identified contingency plans and appear in two or three scenarios. Contingency plans are less robust then a masterplan but also offer insights in the uncertainty surrounding the future electricity grid in the Netherlands. Developments which appear in three scenarios have a higher degree of robustness than developments which appear in two scenarios. The first and second section have the same structure as the scenarios. Every variable in the scale of the conceptual model will be analyzed in the scenarios to determine which developments occur in which scenarios. The third section will give an overview of the identified similarities in table 4 and will place the identified masterplan and contingency plans in the masterplan and contingency plans developed in section 3.2.2 (figure 27). The last section of this chapter consists of a deeper analysis of the identified masterplan and contingency plans. This will be done by elaborating on the identified masterplan and contingency plans and by comparing the scenarios as a whole with each other. Altogether the goal of this chapter is to generate results which offer insights in the uncertainty of the electricity grid in the Netherlands in 2035-2040 and can answer the main research question. Developments which only occur in one scenario are not considered as part of a contingency plan.

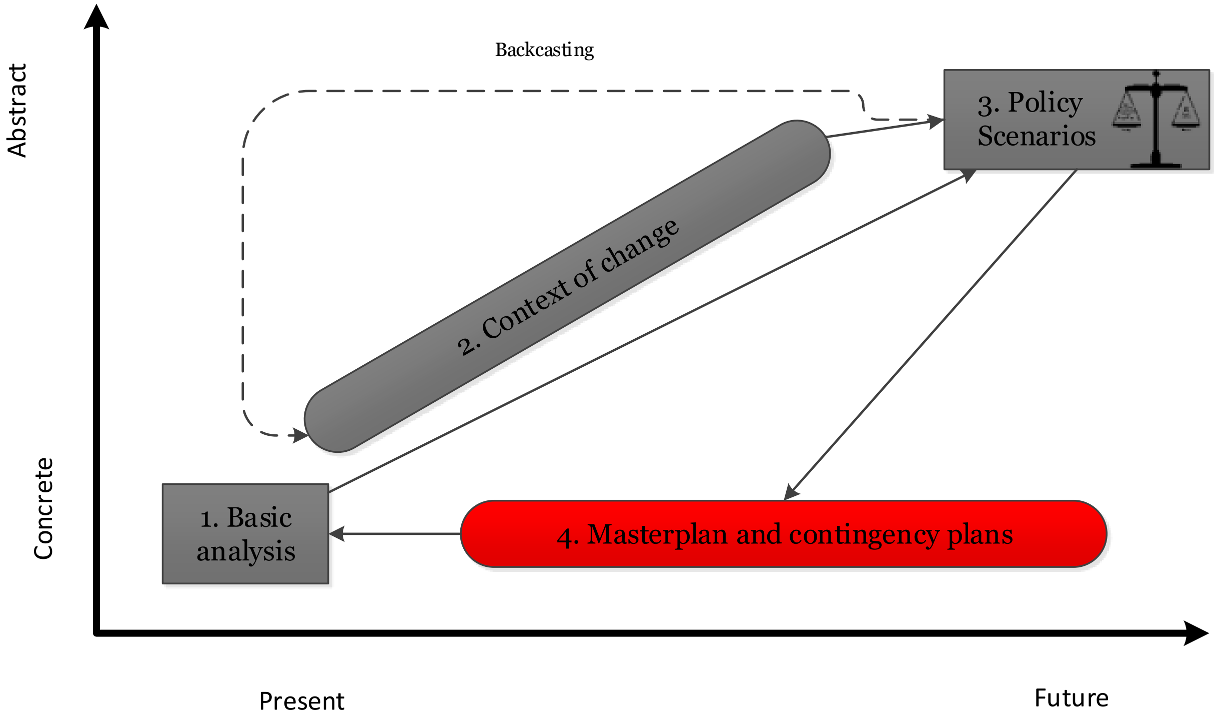


Figure 56: step 4 of the conceptual model

5.1 Masterplan

This part will discuss the developments which appear in all four scenarios and are developments which high likelihood to appear in the electricity grid in the Netherlands in 2035-2040. After analyzing all scenarios, it became clear that no real robust developments are identified. What is present in all scenarios are EE measures but EE measures are already applied in the current situation. No real development has taken place concerning EE measures except that they are intensified in the scenario. In the decentral scenarios the EE will be higher because the generation of the electricity takes place closer to the place of consumption which will reduce transport costs. In all scenarios the EV has penetrated the market further but the percentages differ per scenario and also V2G and the charging method makes a difference at the EV.

Another notable development is energy storage. All four scenarios use energy storage as a way to balance the electricity grid which means energy storage can be considered as the most important way of balancing the electricity grid in general. The storage methods however differ per scenario, where hydrogen is used as a storage method at the central scenarios, V2G is used as a storing method in the decentral scenarios. These different storing methods also have a different impact on the spatial environment. At the other variables also no masterplan has been identified. Although it is debatable if EE measures and Energy Storage are part of a masterplan they are not considered as a masterplan because firstly EE measures are already applied in the current situation and secondly because the spatial implications for energy storage are completely different in the scenarios.

5.2 Contingency plans

Conventional energy sources

During the energy transition conventional energy sources play an important role. Not all scenarios have the same amount of renewables and even when scenarios have the same amount of renewables within the conventional energy sources there can be a difference. The most notable development of conventional energy sources is that in three out of four scenarios coal power plants have been outsourced. Gas power plants are preferred above coal power plants. The only reason when coal power plants can be present is when the Dutch national government decides to apply CCS which suits better to coal power plants than gas power plants. As mentioned in the current situation, currently coal power plants still generate an approximate 20% of the total electricity which also means that the coal power plants still have an influence on the spatial environment. The absence of coal power plants will consequently have an influence on the spatial environment, hence outsourcing coal power plants is considered as a contingency plan.

Another short notice can be made at the presence of gas turbines in the “Strong European Grid” and “The smartest of Grids” scenarios where in both scenarios gas power plants are responsible for 20% of the conventional energy sources. However, it is not surprising when coal is outsourced in three out of four scenarios that gas is responsible for the full conventional energy generation in three scenarios. The amount of conventional energy is incorporated in the outline of the scenarios which makes it more a consequence of the scenario outline than a specific development within the scenarios. Hence the characteristic of 20% renewables in the above mentioned scenarios is not considered as a contingency plan.

Renewables

The pace of the energy transition is characterized by the penetration of renewables, which on their turn are incorporated in the characteristics of the scenario. Hence the percentages of renewables in the scenarios are not considered as a contingency plan. What is identified as a contingency plan is the presence of large offshore wind parks in both central scenarios (Empowering the North Sea and Strong European Grid). When the electricity grid in the Netherlands develops towards a sustainable centrally organized electricity grid the North Sea will most probably be used to apply offshore wind parks on a large scale.

On the other hand, when the electricity grid is organized mostly on a decentral level solar pv will play the most important in the pace of the energy transition. Small local initiatives play an important role in both decentral scenarios (Local Heroes and Smartest of Grids). In both decentral scenarios the urban area plays an important role in the penetration of solar pv, hence both decentral scenarios have a significant impact on the spatial urban environment.

Due to the low capacity of the decentral electricity grid both decentral scenarios demand a certain amount of geographical dispersion. One part of the decentral grid simply does not have the capacity to transport enough electricity for another region. Subsidiarity is one of the points of departure in both decentral scenarios and becomes more important when the amount of central conventional energy sources diminishes. Decentral governments become more important when the grid is organized more decentral because every region becomes more responsible for their own generation of electricity.

What lastly can be identified as a contingency plan is that as renewables penetrate further it becomes more important to have a mix of renewables. As renewables penetrate further peak and off-peak moments become more severe, which causes problems for the stability of the electricity grid. A mix of renewables will make the peak and off-peak moments less severe because they peak and off-peak moments mostly do not coincide. Hence, both 80% renewable scenarios (Strong European Grid and Smartest of Grids) have a mix of renewables to deal with the intermittency problems. The scenario “Strong European Grid” has wind as the main source and solar pv as the supporting source of renewables and the scenario “Smartest of Grids” vice versa.

Energy storage

In all four scenarios energy storage is present but the precise method differs per scenario. A dichotomy can be made between central storage and decentral storage. In both central scenarios electrolyze is used to make hydrogen from abundant (wind) energy. Due to transport losses electrolyze is applied near the source of generation. This means that in both central scenarios hydrogen is created near the shore of the North Sea (Empowering the North Sea) or in the middle of the North Sea (Strong European Grid).

On a decentral level V2G is used as the main source of energy storage. To avoid transport losses again storage is done closest to the source. This means that V2G is applied on the “lokale distributienet” in the scenario Local Heroes with individual charging poles as the connector to the grid. In the scenario Smartest of Grids most of the electricity generation takes place on the “regionale distributienet”. V2G is applied on this part of the grid to avoid transport losses and is done via large central locations where the self-driving vehicle are stationed. These large central locations apply induction charging and automatically manage the storage of electricity by communicating with the self-driving vehicles. Self-Driving vehicles can be added or removed as a storing device depending on what the grid demands. The other way around vehicles can also be connected to feed the grid with electricity when demand exceeds the generation. V2G is applied on different parts of the grid but are in both scenarios the way of storing energy. Hence V2G is considered as a contingency plan in both decentral scenarios.

DSM

In the decentral scenarios DSM has developed further and plays an important role in balancing the electricity grid. In both scenarios DR and fully flexible energy pricing have been applied, which adds a certain amount of “smart” to the electricity grid. Near future prediction of electricity generation becomes and important aspect to accurately predict the near future electricity price. The real team electricity pricing gives economic incentives for EV owners to provide their vehicle for storage (V2G). The car is charged on moments electricity is the cheapest and gives back electricity to the grid on moments electricity is expensive. Also smart household machines, like washing machines are used on moments electricity is the cheapest. Both developments demand involvement of individuals and suits the most to decentral scenarios.

Interconnectivity

The third balancing method which has been identified is interconnectivity. Especially for the Netherlands, a country with a small surface, interconnectivity is important. Due to the size, the Netherlands is mostly subjected to one weather system which means peak and off-peak generation moments will be more severe than a larger country which is subjected to several weather systems. An increasing interconnectivity is present in three out of four scenarios (Empowering the North Sea, Strong European Grid and The Smartest of Grids) which shows the importance of interconnectivity. Both the penetration of renewables and the central/decentral oriented aspect have an influence on the interconnectivity. A central oriented grid is less focused on consuming electricity on the place it is generated than a decentral scenario. This makes it more interesting to seek international collaboration. When renewables take a larger share of the total electricity generation, additional measures are needed to keep the grid stable. Hence in the 80% renewables scenarios interconnectivity is stimulated. This has resulted in two scenarios (Empowering the North Sea and The Smartest of Grids) which has a moderate focus point on interconnectivity. In both scenarios one of the characteristics for a better interconnectivity is present. In the scenario Strong European Grid both characteristics are present. In this scenario, as the name suggests, interconnectivity benefits are optimized and are one of the most important characteristics of the scenario. What should be noted is that the interconnectivity in the scenario Strong European Grid is focused on a few central points where all the national grids meet and in the scenarios Empowering the North Sea and The Smartest of Grids the interconnectivity is organized only between the Netherlands and one neighboring country. No large hubs are created where all national grids of the North Sea countries meet in these scenarios. Altogether three out of four scenarios focusses on a better interconnectivity and all combined form a contingency plan.

EV

The electric vehicle appears in all scenarios but between the scenarios there is a difference concerning the EV. The first notable difference is that in the scenario Smartest of All Grids the electric vehicle is not a Plug-in electric vehicle but an electric vehicle which is charged with induction charging. Besides this the technological developments have changed the conventional vehicle to a self-driving vehicle. Technological advances have changed the automobile as a whole and this has also changed the environment. Cars are not parked in neighborhoods but on large central locations. Also the charging infrastructure differs from the other scenarios. In all other scenarios the PEV is still the dominant type of electric vehicle. The PEV demands a charging pole infrastructure which will be visible in especially the urban areas. Between the three remaining scenarios two scenario have a penetration of 50% of the PEV (Local Heroes and Strong European Grid). These two scenarios will have a similar influence on the physical environment. It should be noted that between these two scenarios one has applied V2G (Local Heroes) and one has not applied V2G (Strong European Grid). V2G is however is considered as a. energy storing method and will not be considered as a difference in this section, hence the PEV is considered as a contingency plan appearing similar in the scenarios Local Heroes and Strong European Grid.

Grid Investments

A few developments have influence on the demanded grid investments. The replacement of conventional energy sources for renewables also demand a connection to the electricity grid. Renewables appear in different forms in the scenarios and all demand their own connection on the electricity grid. For the specific contingency plans focused on renewables, these investments concern connecting offshore wind and connecting urban solar to the electricity grid. There is however a difference between the demanded investments. Offshore wind energy demands new connections to the current electricity grid whereas urban solar is already connected to the electricity grid. The current electricity grid is highly centralized and the decentral part of the grid is mainly used to deliver electricity to the customer. When urban solar becomes a more important source of renewables this also puts a higher burden on the "lokale distributienet". This burden demands investments in upgrading this part of the electricity grid.
What in general can be stated is that as the grids transforms from a central towards a decentral electricity grid, upgrading investments are needed on the decentral electricity grid to deal with the increasing burden. The current decentral electricity grid simply is not build to manage the extra burden.
Another development which demands additional grid investments is the increasing demand for electricity. A decentral oriented scenario has in general a higher demand of electricity because the electrification is expected to go faster in a decentral scenario (CPB & PBL, 2015). This is caused by a faster penetration of the electric vehicle and a replacement of conventional heating by heat pumps. Altogether the demanded grid investments in a decentral scenario are much higher than in a central scenario. In both decentral scenarios the "lokale distributienet" needs to be upgraded to cope with the increasing demand of electricity and also to integrate urban solar energy hence upgrading the "lokale distributienet" is a contingency plan. The upgrading of the lokale distributienet is demanded due to different factors influencing the grid. The connection of offshore wind parks, PEV grid investments, urban solar and a mix of renewables in the 80% renewable scenarios are directly related to the developments in the previous described variables. Because these developments are directly related to these developments in the different variables they will not be recognized as contingency plans for grid investments.

5.3 Summarizing the contingency plans

In the table 4 below the masterplans and contingency plans are summarized and show in which scenarios they appear. No masterplans have been identified, 2 contingency plans which appear in three scenarios and nine contingency plans which only appear in two scenarios. Contingency plans which occurs in three scenarios have been made grey and contingency plans which occur in two scenarios are white. On the bottom of this table the masterplans and contingency plans per scenario are added up to the total amount of plans per scenario. Below the table figure 57 shows the visual representation of all contingency plans based on the figure 27 in section 3.2.2.

	The Scenarios				
Master and contingency		*Empowering the North Sea*	*Strong European Grid*	*Local Heroes*	*The Smartest of Grids*
	Outsourcing coal		X	X	X
	Offshore wind	X	X		

	Urban Solar			X	X
	Mix of renewables		X		X
	Hydrogen	X	X		
	V2G			X	X
	Smart Household Machines			X	X
	DR – fully flexible energy prices			X	X
	Interconnectivity	X	X		X
	50% PEV		X	X	
	Upgrading lokale distributienet			X	X
	Masterplans	0	0	0	0
	Contingency plans 3/4	1	2	1	2
	Contingency plans 2/4	2	4	6	6

Table 4: Summarizing the contingency plans

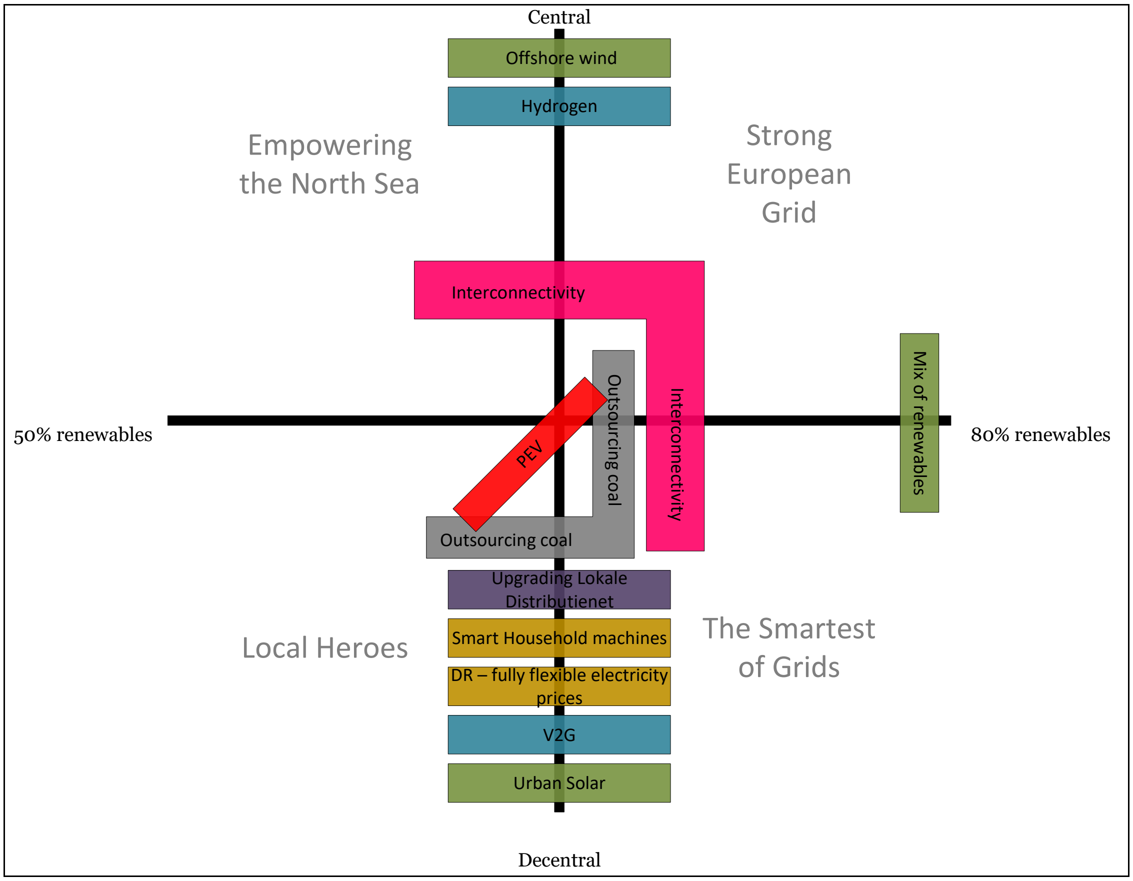


Figure 57: Visual representation of the identified contingency plans

5.4 Analysing the scenarios and contingency plans

A few conclusions can be drawn concerning a masterplan, contingency plans and the comparison of the scenarios. Firstly, no masterplan could be identified after comparing the scenarios which means no developments can be identified that offer the most insight in the electricity grid in the Netherlands in 2035-2040. However, two developments have been identified which seem highly plausible it will occur. Both a better interconnectivity and the outsourcing of coal appear in three out of four scenarios. Furthermore 9 contingency plans have been identified which appear in two out of four scenarios, which also offer insights in the uncertainty of the electricity grid in the Netherlands in 2035-2040. Taking a closer look at figure 57 the following can be concluded

1) Between the scenarios it is notable that Empowering the North Sea has the least contingency plans (three) and The Smartest of Grids has the most contingency plans (eight). This could be explained by comparing the scenarios to the current situation of the electricity grid. Currently electricity generated by solar and wind energy only contribute 8,3% to the total generated electricity in the Netherlands, as pointed out in section 4.2. The remaining electricity is mostly generated on a central level with conventional energy sources. Hence, the current electricity grid in the Netherlands is highly centralized with a low penetration of renewables. Taking this in consideration, of the four scenarios, the electricity grid in Empowering the North Sea has the most in common compared to the current situation, since it has a relative low penetration of renewables and is also highly centralized. Consequently, less developments are needed to achieve the scenario Empowering the North Sea, compared to other scenarios. This again decreases the change of identifying contingency and masterplans. For the scenario The Smartest of Grids this reasoning can also be applied only exactly the other way around. This explains that the scenario The Smartest of Grids contains the most contingency plans.

2) The scenarios Empowering the North Sea and Local Heroes have nothing in common while all other scenarios do have certain aspects in common. This is a surprising conclusion because at a first glance it seems that scenarios which are exactly opposite of each other seems the most different scenarios. When renewables penetrate further to 80% it can be expected that a decentral or central scenarios develops more distinguished. However also both 80% renewable scenarios do have certain characteristics in common.

3) Contingency plans are shown more in a horizontal direction than in a vertical direction in figure 57. Taking this in consideration it can be concluded that the Central/Decentral aspect is a more determining factor for the future electricity grid in the Netherlands then the 50%/80% renewables aspect.

4) Analyzing the types of balancing methods identified in the theoretical framework and interviews it can be stated that the Central and Decentral scenarios both have different preferences of balancing methods. The central scenarios prefer a better interconnectivity combined with energy storage. The Decentral scenarios prefer DSM combined with energy storage. Though in the scenario Smartest of Grids interconnectivity also plays a role as a balancing method, it was pointed out by interviewer 2 that interconnectivity was not the preferred way of balancing a decentral oriented grid. Interviewer 2 explained that to keep the efficiency has as high as possible it was desired to consume the electricity close to the place it was generated. However, interviewer 2 also mentioned that at a certain point, when electricity by renewables have a large shore of the total generated electricity, it was inevitable that a better interconnectivity was also needed.

6. Conclusion

The publication of the report "Limits to the growth" in 1972 has caused societal awareness about how mankind is currently depleting natural resources of the earth. Sustainability became an increasing important subject of many societies in the world. One of the subjects of sustainability is the current use of different energy sources. The urge for a more sustainable future also had its influence on the electricity system in the Netherlands. Currently the electricity grid in the Netherlands is still relying heavily on unstainable energy sources. The change towards a sustainable electricity system are going to change the Dutch (spatial) environment. However, many aspects are still uncertain and the goal of thesis is to offer insights in the uncertainties of the future electricity grid in the Netherlands. The main goal of this thesis is to gain insights in the uncertainties of the future electricity grid in the Netherlands with the main research question:

"How can scenario planning offer insight in the uncertainties which go hand in hand with the energy transition and the implication for the electricity grid in the Netherlands in 2035-2040?"

The goal of the Dutch energy transition is to become CO_2 neutral in 2050 (Ministerie van Economische Zaken, 2017a). This means that the Dutch government want to repulse 95% of the CO_2 in 2050. Currently the electricity system in the Netherlands generates an approximate 8,3% of its total electricity with renewables and the remaining electricity is generated with conventional non sustainable energy sources (CBS, 2017a). The energy transition demands a radical change in the electricity system with which comes along many uncertainties.

The most promising aspects identified in the literature, summarized in chapter 2.6 matched with most parts of the results. What was not identified in theoretical framework was that the size of the electricity grid is an important balancing method as well. The size of the electricity grid is a balancing method because a single weather system usually has more influence on a smaller electricity grid than a larger electricity grid. For the electricity grid in the Netherlands this had the consequence that a better interconnectivity with neighboring electricity grids was an import balancing method. The most promising aspects identified in the theoretical framework have been used consistently to develop the scenarios.

Scenario planning can be used on various way with various purposes. To give insights in uncertainties scenario planning should not be used as a goal but as a means. The purpose of scenarios as a mean to gain insights in uncertainty is by comparing them. Developments which appear in all scenarios have a high likelihood to appear in the future and developments which appear in no scenario have a small low chance to appear. However, to make the scenarios easy for comparison, developing scenarios in a consistent way is important. By identifying the most promising aspects for the electricity grid in the Netherlands in 2035-2040, the scenarios where suited for comparison.

The most promising aspects where divided in six categories of which five where identified in the theoretical framework and one was identified with the data collection. Aspects which have been identified where Conventional energy sources, Renewables, Energy Storage, Demand Side Management, Interconnectivity and the PEV. These aspects where systematically described in the developed scenario: Empowering the North Sea, Strong European Grid, Local Heroes and The Smartest of Grids. By comparing these scenarios nine contingency plans have been identified.

Having developed the scenarios and made them suitable for comparison, an answer can be given on the main research question:

"How can scenario planning offer insight in the uncertainties which go hand in hand with the energy transition and the implication for the electricity grid in the Netherlands in 2035-2040?"

Scenario planning can give insights in the uncertainty of the future electricity grid in the Netherlands by using scenario planning as a means not as a goal. By comparing the developed scenarios, a masterplan and contingency plans can be developed. Developments which appear in all four scenarios have a high likelihood to appear in the future and can be part of a masterplan. Developments which appear which appear in two or three scenarios also have a certain degree of robustness and can be part of contingency plans. To make the scenarios suitable for comparison it is recommended to apply the same structure in every scenario.

By comparing the scenarios Empowering the North Sea, Strong European Grid, Local Heroes and the Smartest of Grids insights in the uncertainties have been identified for the specific case of the electricity grid in the Netherlands in 2035-2040. Table 5 summarizes the insights which have been found. Below this table these insights will be briefly addressed.

	The Scenarios				
Master and contingency plans		*Empowering the North Sea*	*Strong European Grid*	*Local Heroes*	*The Smartest of Grids*
	Outsourcing coal		X	X	X
	Offshore wind	X	X		
	Urban Solar			X	X
	Mix of renewables		X		X
	Hydrogen	X	X		
	V2G			X	X
	Smart Household Machines			X	X
	DR – fully flexible energy prices			X	X
	Interconnectivity	X	X		X
	50% PEV		X	X	
	Upgrading lokale distributienet			X	X
	Masterplans	0	0	0	0
	Contingency plans 3/4	1	2	1	2
	Contingency plans 2/4	2	4	6	6

Table 5: Summarizing the contingency plans

The first important conclusion which can be drawn is that no development appears in every scenario, hence no masterplan could be identified. Consequently, planners should recognize that no plans can be executed without deciding how the electricity grid in the Netherlands should develop in the future. This fundamental uncertainty ultimately demands decisions from decision makers which include certain developments, but also exclude other developments. Careful consideration of different options is important as adjustments on the electricity grid usually demands high initial investments which can create a lock-in. Postponing decision is another option but this can delay the energy transition and eventually result in failing to achieve the goal of the Dutch national government to reduce the expulsion of greenhouse gasses with 95% in 2050.

The second important conclusion is that many contingency plans, which offer a degree of certainty, have been identified. With a high degree of certainty, it can be expected that coal power plants will be disappeared from the in the period 2035-2040. The only scenarios in which electricity is still generated with coal power plants is the scenario Empowering the North Sea. In all other scenarios gas power plants are preferred above coal power plants. The second development which has a high degree of certainty is a better interconnectivity with neighboring countries. Only in the scenario Local Heroes no additional investments are made for a better interconnectivity with neighboring countries. Both interviewer 1 and 2 pointed out that interconnectivity for a small country as the Netherlands is especially important. Smaller countries are usually affected by one weather systems which makes the peak and off peak generation moments of renewables more severe than in a larger country.

Furthermore, nine contingency plans have been identified. If the electricity grid stays centrally organized the main source of renewable output will be offshore wind and the storing method in which abundant electricity is stored is hydrogen. If the electricity grid becomes decentral organized, it is certain that urban solar will be the main source of renewable output. Storing energy is on the decentral electricity grid is done in the electric vehicle with V2G. V2G and smart household machines are stimulated with DR and fully flexible electricity prices. Interviewer 1 and 2 have pointed that influencing the demand side with fully flexible electricity pricing is an aspect which adds the “Smart” to the grid.

Due to the shift from a central to a decentral electricity grid investments are needed in upgrading the “lokale distributienet”. The current lokale distributienet is simply not build to accommodate the generation of electricity.

A contingency plan concerning both 80% renewable scenarios is that a mix of renewables is needed to keep the grid stable whereas both 50% scenarios only need one type of renewable. This is caused by the intermittency of renewables which becomes more severe when they take a larger share of the total generated electricity.

The last notable contingency plan is the presence of the PEV and the charging infrastructure which is similarly present in both the Local Heroes and Strong European Grid scenarios.

7. Discussion

This part will further discuss the results and the conclusion of this thesis. Despite no masterplan for the future electricity grid in the Netherlands could be identified, many contingency plans have been identified. To reflect on these contingency plans, the whole process from the empty scenario framework to the contingency will be critically discussed. The whole process will be analyzed by (1) discussing the empty scenario framework, (2) the development of the scenarios and the presence of the variables discussed in the theoretical framework, (3) the contingency plans which have been identified. After this (4) the value of the thesis for planning theory and planning practice will be discussed and (5) suggestions will be made for future research. Lastly (6) the conceptual model and findings will be put in a broader perspective.

After the theory of scenario planning was discussed an empty scenario framework had to be made, which could be use as point of departure for developing the scenarios. In section 3.3 several options have been considered for the empty scenario framework used in this thesis. The influence of the final empty scenario framework on the progress of the following chapters is enormous. A possible option which is considered at the end of the thesis is instead of dividing the scenario framework into central/decentral and the percentage of renewables is dividing the scenarios in three parts of the grid (central – middle – decentral) with one percentage of renewables (somewhere between 50% - 80% renewables). The current pairs of central and decentral scenarios seem to have a lot in common and sometimes the 80% scenarios seem an upgrade of the 50% scenarios. This is especially the case with the central scenarios.
The advantage of using two different percentages on the other hand has clearly shown that additional balancing methods are needed to keep the grid stable. An interesting aspect which could only be shown with the different percentage of renewables is the need for a mix of renewables. Both interviewers pointed out that this will greatly reduce peaks of intermittency problems. The concluding note concerning the empty scenario framework that it has an enormous influence on the conclusion, something which has not totally been considered at the beginning of developing the scenario framework.

The development of the scenarios by describing the presence of the different variables seems logical. Especially the central scenarios were an easy process which seems a logical consequences of the prerequisites of the scenarios. What should be noted concerning the energy storage methods is that developments have gone rapidly the last few years and numerous possibilities where available to both central and decentral scenarios. Especially the desk research showed numerous possibilities. Both interviews where especially important to decide the right type of storing for every scenario. However due to the numerous developments of energy storage and energy storage still only being applied in pilot projects in the Netherlands, the preferred storing method can change at any moment.
A specific problem for the decentral scenarios is that the whole energy system is considered in policy documents of decentral developments whereas in the central scenarios the electricity grid can be more separated from the energy system. An example of this is given by Van Kann (2015) which describes Exergy plans for different regions. This is explained by the relative short distance heat can be transport over due to the high energy loss during transport. This was also pointed out by interviewer 2 who mentioned grid integration several times in decentral developments. This thesis however focusses only on the electricity grid, and these developments have been left out of consideration. The last notable observation is that between both decentral scenarios the focus changes from the lokale distributienet to the regionale distributienet. The lokale distributienet is not build to cope with a large amount of renewable capacity which is a logical explanation for the relative low penetration of renewables in Local Heroes and the higher penetration of Smartest of Grids. But the Smartest of Grids focusses more on the “middle” part of the

electricity grid and with some adjustments could also be used as a middle grid scenario mentioned in the previous section.

The contingency plans which have been identified are debatable because in the scenarios the spatial consequences of the identified contingency plans are not completely similar. The line between a contingency plan and not being a contingency plan cannot be determined as strict as expected. Sometimes the decision is not made completely rational but sometimes also (partly) intuitional. For example, the contingency plan Interconnectivity. Two scenarios have a “moderate” focus on interconnectivity and one scenario has an “extreme” focus on Interconnectivity. Should the “extreme” focus on Interconnectivity also be considered as a contingency plan or should it not be considered as part of this contingency plan? More off these dilemma`s appeared and sometimes the answer was not as black as white as it was desired. As the contingency plans offer insights in the uncertainties surrounding the electricity grid in the Netherlands in 2035-20400 this is an important shortcoming in this thesis.

The practical results and the selected theoretical approach have proven its value for planning in general. On the theoretical aspect, scenario planning has been used as an approach to offer insights in the uncertainties of the electricity grid in the Netherlands in 2035-2040. Planning often is aimed on a longer time horizon, and as the time horizon increases uncertainties usually increases, which is also the case for this thesis. This is also pointed out by De Roo & Hillier (2016) which discuss a shift from blue print planning towards more flexible planning due to the many uncertainties which are faced in the future. Scenario planning is especially suited to offer insights in the uncertainties in the uncertain future. The results have proven the practical use of scenario planning for this specific subject. Insights in uncertainties have been identified about specific possible developments, and the spatial consequences these developments will have. These insights in the uncertainties are described in the contingency plans which have been identified via scenarios.

This thesis has shown different possible future of the electricity grid in the Netherlands in 2035-2040. The scenarios however do not describe in detail how institutions have to be arranged for a smooth development towards the specific scenarios. As already discussed in the theoretical framework, transition theory can offer insights in how institutions should be arranged to empower a transition. As already shortly mentioned in the context of change of all scenarios, involvement of society can be an important aspect determining the direction of the system. It is highly plausible that the institutional arrangement should be different in the Empowering the North Sea scenario than in the Smartest of Grids scenario. But which institutional arrangement suits the most to for example a central or decentral scenario is an interesting research subject.
Other interesting research subjects can be focused on one specific variable or the interrelationship of two variables. An example of this can be if the storage of energy into hydrogen affects the penetration of the hydrogen powered car or how different charging techniques of the EV will change the spatial environment.

The conceptual model which has been developed has proven to be an effective tool to compare different scenarios concerning the electricity grid of the future. In general, the four step scenario approach can be applied on different electricity grids on various time scale. Also the general categories (Conventional energy sources, Renewables, Energy Storage, DSM, Interconnectivity and the PEV) which structure the scenarios can be applied in general. However, the scenarios which can be developed with the four steps process will be specific for every individual electricity grid.
The process of developing scenarios goes from generic to specific when all the identified categories are analyzed for the specific electricity grid. In another country with other geographical characteristics for

example another type of renewable can be electricity generated with hydro power. Also some energy storing methods demand certain geographical characteristics which can have an influence on the identified categories.

Altogether it can be stated that the generic applicability of the conceptual model becomes more specific when within the categories the promising aspects are identified. The scenarios which are developed are composed with the specific aspects identified in the categories, hence the scenarios are also only applicable for the specific electricity grid which is being researched. As the masterplan and contingency plans are identified by comparing the scenarios these plans are also scenario specific.

Concluding it can be stated that the approach described in the conceptual model is general applicable but the outcomes which offer insights in the uncertainties of the future electricity grid will by specific for every case and cannot be generalized.

8. Reflection

This chapter will reflect firstly on the theoretical framework, secondly on the methodology and the last part will be a self-reflection.

The theoretical framework consists of two parts. Firstly, different promising aspects for the future electricity grid has been discussed and secondly the most suited approach to deal with uncertainties is determined.

Knowing only little about the future electricity grid selecting the most promising aspects was a difficult task. Dividing the different aspects into generation methods, balancing methods and the PEV has proven to be valuable for future research. For future research on this topic this simple separation can offer a workable structure. The PEV should be separated from the balancing methods because when V2G is applied the PEV can be a storing method but when V2G is not applied it cannot be used as a storing method. This was also proven by two scenarios which applied V2G and two scenarios which did not apply V2G.

An aspect which was not explicitly mentioned as a balancing method in the literature review was interconnectivity between neighboring electricity grids. This however proved to be a valuable balancing method for the future electricity grid in the Netherlands. The most probable explanation for this is that most literature is not specifically aimed on the Netherlands. The U.S.A is mentioned a lot in location specific research and due to the size of this country interconnectivity is less important to deal with intermittency problems. For the Netherlands, a small country which is mostly affected by one weather system this interconnectivity is one of the more important balancing methods to smoothly integrate a high percentage of renewables.

A generation method which is not mentioned in this thesis is nuclear energy. This choice has been made deliberately because nuclear energy only has a small contribution to the generated electricity a no concrete plans have been found which state that new nuclear power plants are planned in the Netherlands. However nuclear energy can play an important role in the energy transition. As already mentioned in the discussion the selection of different types of storing methods have deliberately stayed open concluding that many storage methods are possible. Due to the many developments in storing techniques it was difficult to make a pre-set selection of storing methods, hence this has been left open only mentioning a few of the many possibilities.

Scenario planning was selected as the most suitable approach to deal with the many uncertainties surrounding the future electricity grid in the Netherlands. Due to the many uncertainties and low controllability of the electricity system this seemed to be the right approach. Throughout the process of this thesis it has proven to be the most suited approach however, the process of developing useful have scenarios has sometimes been difficult. My limited knowledge about the electricity system as a whole and scenario planning might have contributed to the difficulties which sometimes where faced developing workable scenarios. As the radical desired change of the electricity is instigated by the energy transition, which is by definition a complex phenomenon, the lack of knowledge of the whole energy system could have been expected. In fact, this does not have to be a problem when describing scenarios, when suitable methods are used to gather data.

A method which is often used in developing scenarios is called the Delphi-method. This method consists of a group process where several specialists combined give their input to shape the different scenarios. Usually the development of the scenarios is also part of a cyclical approach where several rounds of the Delphi-method is used to eventually shape the scenarios. This was however ought to time consuming and impossible to organize for a master thesis. Instead the combination of desk research and interviews with specialists have been used. These combination of methods was deliberately chosen because it combines

unbiased secondary data with biased primary data. Documents for the desk research were in abundance and easy to find.
The initial plan was to interview three different persons from three different organizations. One person from TenneT to gather data aimed on the central scenarios, and one interview with a person of Enexis to gather data for decentral scenarios. The third person desired interview was meant for a person from the Planbureau voor de Leefomgeving. This organization already executed a scenario study and the interview was aimed on gaining more information on the spatial consequences in general. Eventually the most difficult part of the data analysis was to correctly value and interpret the collected data due to the lack of specific specialist knowledge of myself.

Reflecting on myself throughout process it can be stated that time management was not the strongest point. Together with the difficulties lack of specific knowledge this had the consequence that the final thesis was finished a few months later than expected. Especially the abundance of sometimes contradicting documents where hard to place in perspective. This took more time than expect and have been a big contributor to delay of the finishing date of this thesis. Now, close to the date the final thesis is handed in I can state that the decision based on the sometimes contradicting documents should have been made earlier.
The interviews have been a great contribution to the final results. I have attempted to ask and formulate the question as neutral as possible to the interviewees to avoid a bias in the question and consequently a bias in the answers. However, it is sometimes difficult to ask unbiased questions as it is easier to ask to things you already know about than asking the things you do not know anything about. Eventually I think I succeeded quiet well in formulating the question as neutral as possible. I think the scenarios, which were developed based on the data collection with the interviews and desk research, are a good representation of the possibility of the electricity grid in the Netherlands in 2035-2040.

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9. Appendix

Appendix 1: Interview guide TenneT

Introductie
Goedemorgen,

Bedankt dat u wilt meedoen aan mijn onderzoek.
Mijn naam is Arno Kastein en ik studeer aan de Rijksuniversiteit Groningen. Hier doe ik de master Environmental and Infrastructure Planning. Voor mijn masterscriptie doe ik een onderzoek naar hoe het Nederlandse elektriciteitsnet zich in de toekomst gaat ontwikkelen. Doordat er veel veranderen gaat (door de toenemende mate van duurzame energieopwekking) is er veel onzekerheid over hoe dit precies georganiseerd gaat worden heb ik gekozen om dit in een scenario study te onderzoeken. Hierin maak ik onderscheid tussen een centraal en een decentraal georiënteerd elektriciteitsnet. Om meer te weten te komen over een centraal georiënteerd elektriciteitsnet heb ik contact gezocht met TenneT en ben ik zodoende bij u terecht gekomen.
Het interview bestaat uit een paar inleidende vragen, een paar vragen over het thema en als laatste nog een paar afsluitende vragen. Het interview duurt ongeveer een uur maar dat is natuurlijk ook afhankelijk van hoeveel u met mij kan delen. Daarnaast kan u altijd aangeven dat u een pauze wilt houden. Als u ermee akkoord gaat dan zou ik graag het gesprek opnemen zodat ik beter kan luisteren en minder hoef op te schrijven. Ook kan ik dan het gesprek nog een keer luisteren zodat ik eventuele gemiste dingen alsnog kan achterhalen. Als u wilt dat uw naam niet genoemd wordt in het onderzoek zou ik ook een pseudoniem kunnen gebruiken of uw als werknemer van TenneT kunnen duiden in mijn scriptie. Als u geïnteresseerd bent in mijn scriptie zou ik u een kopie kunnen opsturen als deze afgerond is.
Voordat we beginnen met het interview; Heeft u nog vragen? Gaat u ermee akkoord dat ik het gesprek opneem?
* Nadat ik de recorder heb aangezet ga ik u deze vragen nog een keer stellen.

Inleidende vragen
- Wat is uw opleidingsachtergrond?
- Hoe bent u bij TenneT terecht gekomen?
- Waar heeft u al aan gewerkt binnen TenneT?

- Wat is uw specifieke functie binnen TenneT?

Primaire vragen over het thema

<u>Belangrijkste input voor het elektriciteitsnet</u>
Wind
1. Duurzame opwekking gaat een steeds prominentere rol innemen in ons energiesysteem. Waar verwacht u dat de opwekking van windenergie voor Nederland het meest gaat plaatsvinden?
- Verwacht u dat er gekozen wordt voor een geografische spreiding van windmolens of dat de meest efficiënte locaties de belangrijkste rol gaat spelen in het toewijzen van windmolen locaties.

Zon
2. Verwacht u dat het opwekken van energie door zonnepanelen een grote rol gaat spelen op het centrale net d.m.v. grote zonnepanelen complexen
- Zo ja zijn wat zijn kenmerken van deze locaties? En zijn er al locaties bekend waar dit gaat gebeuren?

Opslagmethodes
3. Naarmate duurzame energieopwekking een groter deel gaat uitmaken van onze totale energieopwekking wordt het stabiel houden van het elektriciteitsnet een steeds grotere uitdaging. De opslag van elektriciteit wordt hiervoor vaak genoemd als oplossing. Verwacht u dat de opslag een belangrijk aspect gaat worden en zo ja welke vormen van opslag zijn er op dit moment het kansrijkst?
- Zijn dit opslagmethodes die je kan categoriseren als centrale of decentrale methodes?
- Zijn deze methodes locatie gebonden?

Demand side management
4.Is het realistisch om te verwachten dat de samenleving zich gaat aanpassen aan het aanbod (piek belasting verminderen)
- Is hier de prijs van elektriciteit de belangrijkste prikkel?

De elektrische auto

5. De elektrische auto wordt zowel genoemd als extra belasting voor het elektriciteitsnet alsmede ook als opslagmethode. Is de elektrische auto een betrouwbare opslagmethode (vehicle to grid) in gedachte houdende dat je mensen niet kan verplichten deze altijd aan te sluiten op het elektriciteitsnet?
- Hoe ver moet het oplaadnetwerk ontwikkeld zijn? Is een landelijk ontwikkeld oplaadnetwerk nodig om de elektrische auto tot betrouwbare opslagmethode te ontwikkelen?

<u>De infrastructuur van het net</u>

6. Welke infrastructurele aanpassingen van het net zijn er nodig om het voorheen besproken te realiseren?

7. Is een betere verbinding met het buitenlandse net nodig om een groter deel duurzame opwekking te bewerkstelligen?
- Zo ja welke verbindingen zijn er dan het meest voor de hand liggende?

Externe factoren

8. De opslag van CO_2 lijkt een oplossing om het uitstoten van CO_2 in de lucht terug te dringen. Wat gaat deze opslag betekenen voor de toename van duurzame energie op ons elektriciteitsnet?
- Zou je kunnen stellen dat de opslag van CO_2 er voor gaat zorgen dat de toename van duurzame energie wordt geremd?

Appendix 2: Interview guide Enexis

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- Zou je kunnen stellen dat de opslag van CO_2 er voor gaat zorgen dat de toename van duurzame energie wordt geremd?

Appendix 3: Coding scheme

Theme	Code	Type	Description
Introduction questions	Educational background	Deductive	What is your educational background?
	Company	Deductive	Why did you start working at this company?
	Performed activities	Deductive	What kind of work did you do at your company?
	Function within the company	Deductive	What is your specific function at your company?
Generation methods	Solar	Deductive	What are your expectations of solar energy in the future?
	Wind	Deductive	What are your expectations of wind energy in the future?
	Other	Deductive	What kind of other generation methods with potential are there?
	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?
Storing methods	Type of storing	Deductive	What type of storing methods do you expect in the future?
	Location of storing	Deductive	Where will these storing methods be located?
	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?

Demand side management (DSM)	Energy Efficiency (EE)	Deductive	In what ways can you increase the EE in the Netherlands?
	Time of Use (TOU)	Deductive	How should TOU be used in the Netherlands?
	Demand Response (DR)	Deductive	What’s your opinion about DR and the effect of it on the Dutch electricity grid?
	Spinning Reserves (SR)	Deductive	What’s your opinion about SR and the effect of it on the Dutch electricity grid?
	Smart Grid	Deductive	When is an electricity grid a Smart Grid?
	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?
PEV	Vehicle to Grid (V2G)	Deductive	Can the PEV be used as a reliable storing method of electricity?
	Burden for the electricity grid	Deductive	What is the impact of the PEV, with V2G, on the electricity grid?
	Charging method	Deductive	How should charging of the PEV be done?
	Self-driving vehicle	Inductive	What is the impact of the self-driving vehicle on the electricity grid?
	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?
Electricity grid	Local/ Regional adjustments	Deductive	What kind of adjustments has to be done on a local/regional level?
	National adjustments	Deductive	What kind of adjustments has to be done on a national level?
	International adjustments	Deductive	What kind of adjustments has to be done on an international level?

	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?
CCS	Impact on the grid	Deductive	What is the impact of CCS on the grid?
	Impact on the electricity mix	Inductive	What is the impact of CCS on the electricity mix?
	Location	Deductive	What are the geographical demands of CCS?
	Spatial	Inductive	What is the spatial impact specifically for the Netherlands?
High potential developments	Central	Inductive	What developments have a high potential for a central oriented electricity grid in the Netherlands?
	Decentral	Inductive	What developments have a high potential for a decentral oriented electricity grid in the Netherlands?

Appendix 4: Transcribed and coded interview TenneT

I: (...)
G: Ik hou mij al heel lang bezig met de ontwikkeling van het transportnet. Wij moeten iedere 2 jaar aan de toezichthouder een document overhandig waarin we zeggen wat onze plannen voor de komende 7 tot 10 jaar zijn.Het kwaliteits en capaciteitsdocument. (..)
G: Nu houd ik mij vooral bezig met de langetermijn ontwikkeling van het transportnet. Dus wat gaat er met het hoogsspanningsnet gebeuren als we de transitie naar een duurzame energievoorziening eigenlijk de volgende fase ingaan. Wat moet er in 2050 aanwezig zijn?
I: Dat is de CO2 arme energievoorziening
G: Ja
I: Dan heb ik nog een vraagje met betrekking tot de decentrale en centrale aspecten. Daar worden vaak in documenten van de overheid en als ik literatuur lees wat ik heb moeten doen voor mijn scriptie wordt die vaak heel gescheiden genoemd. Is die scheiding ook echt zo strikt dat jullie het transportnet en het koppelnet hebben en het distributienet, lokaal en regionaal, dat dat voor de regionale.
G: Ja dat is 100 procent gescheiden. Dus wij beheren alle netten vanaf 110Kilovolt en de regionale net bedrijven die hebben alles beneden de 110 Kilovolt.
I: En zijn jullie betrokken bij de ontwikkelingen die meer onderaan het net gebeuren.
G: Ja zeker want in de ontwikkeling van onze capaciteitsplannen, dus waarin we zeggen werk intensief samen met de regionale netbeheerders. En daar wordt ook wel rekening gehouden met wat gaat elektrisch vervoer doen en wat gaat zon pv doen. Dus dat soort zaken. Dus waar mogelijk stemmen we af maar voor ons is steeds belangrijker de samenwerking met GasUnie transportservices dus de Gas infrastructuur want daar gaat veel meer overlap in komen wat wij voorzien.
I: Hebben we het dan over waterstof wat ik heb gelezen dat jullie dat.
G: Ja
I: Maar dat is iets wat er gaat komen.
G: Het is nog niet zeker. Maar het lijkt er wel op.
I: En hebben jullie nu ook al een nauwe samenwerking met de GasUnie.
G: Ja zeker. We werken al op vele trajecten samen. Dus ook in scenario ontwikkeling werken we samen. Ook heel dichtbij ten aanzien van capaciteitsplanning voor gascentrales dat we daar over afstemmen en dat soort zaken. En dat moet ook vanuit Europa. Dus europese wetgeving zegt dat gas en elektriciteitsnetbeheerders moeten meer samenwerken. Maar wij deden dat voor die tijd al. Dus bij verschillende projecten waarin we dus vooruitkijken.
I: Dus er zat al een belang in om dat te doen voordat het verplicht werd.

G: Ja
I: Oke helder.
I: Ik wil het hebben over de energiebronnen hebben. Het is nu nog vooral gebaseerd op kolen en gas. Wat verwacht u wat de dominante of belangrijkste bron gaat worden in een CO2 arm elektriciteitsnet.
G: Voor Nederland. Als het moet. Offshore wind.
I: En dat plan dat er ligt op de Noordzee, is dat voldoende voor Nederland om echt als belangrijke levering te zijn voor elektriciteit of moet er nog veel meer komen naast.
G: Ja daar zijn we nu juist aan het kijken. We denken dat het verduurzamen van puur de elektriciteitsvraag, voor kracht en licht wordt dat genoemd, en voor elektrische auto`s en ook eventueel voor warmtevoorziening dat dat wel lukt. Maar de grote uitdaging wordt de verduurzaming van de chemische industrie. Er gaat heel veel energie als grondstof en ook ter ondersteuning van de processen in de chemische industrie. En er ontstaat nu een beeld dat dat eigenlijk, dat wordt het hoofspel. En de elektrificatie van de elektriciteitsvraag en zo en ook de behoefte aan opslag. Als we de duurzame chemische industrie hebt dan is dan gewoon kinderspel geworden. Het hoofdprobleem komt daar op te liggen
I: Wat is dan precies het probleem met het verduurzamen van de chemische industrie? Hoe moet ik dat zien?
G: Alles wordt nu uit olie of aardgas gegaan en dat moet ook duurzaam worden. Want uiteindelijk wordt een product verbrand ofzo en dan komt ook de CO2 weer vrij. Dus alle chemische producten, en voor ons is dat bijvoorbeeld kunstmest, is een hele belangrijke emitter van CO2 opzich al. Dus daar moet het ook gebeuren maar ook de chemische industrie. Dus alle chemische producten, alle plastics enzo`, moeten ook verduurzaamd worden. Daar heb je dan de route is biomassa zou het kunnen worden samen met waterstof. Dan heb je nog steeds heel veel waterstof nodig en wat bij de biomassa als zeebron dient en waterstof eigenlijk om er echt waterstof van te maken. Daar heb je heel veel energie voor nodig.
I: Oke, nog over de zonne energie met zonnepanelen. Ziet u daar nog grote kansen voor en waarom wel en waarom niet?
G: Het grote probleem is de gelijktijdigheid. Als het zonnig is dan is het in heel Europa vaak zonnig. Dus dan is er een hoog aanbod. Dus dat maakt de inpassing heel moeilijk. En ten tweede, dat noemen wij de bedrijfstijd van het maximum. Dus als je 1Kilowat zon op je dak hebt. Als je dat over het jaar dan levert die zo 900 - 1000 uur op vol vermogen. Dan heb je bij 1 Kilowat dus ongeveer 1000 Kilowat uur. En dat is in een periode waarbij iedereen aan het produceren is. Dus de inpassing ligt daar een stuk moeilijker.
I: Het is ook als je wind energie naast zonne energie legt. Mocht je hetzelfde met zonne energie willen bereiken dan zul je veel meer opslag capaciteit moeten hebben.
G: En ook veel meer geinstalleerd vermogen. Dus off shore heeft een bedrijfstijd van het maximum die 4 keer zo hoog is als zon pv. En daarnaast ook nog eens een keer.
I: Bedrijfstijd?
G:Dat is dus die loodfactor. Als je 1 Kilowat installeerd kan je zeggen over een jaar genomen heb je 4000 uur keer 1 Kilowat. En bij zon is het 800 - 1000 uur.
Dus je haalt uit iedere kilowat haal je veel meer energie en daar komt nog bij dat het in de winter harder waait. Als de vraag hoog is er hoger wind aanbod. Dus dat maakt het makkelijker.
I: De jaarlijkse opwekking van wind energie sluit beter aan bij de vraagkant. Omdat er in de winter ook meer wordt gevraagd voor verwarming enzo.
Oke dus u denkt dat zonne energie een kleine bijrol gaat spelen
G: Nou een kleine bijrol. Een bijrol.

I:En dat is dan vooral decentraal niveau. Op daken van huizen. Niet zoals in Duitsland die grote zonnepanelen.
G: Die komen nu wel maar op een gegeven moment houdt het op. Afgelopen zondag waren de elektriciteitsprijzen in Duitsland negatief. Dus je moet betalen om het op het net te zetten. En dat ga je met zon veel meer krijgen dat je niks met je elektriciteit kan. Dan kan je nog wel een accutje neerzetten maar daar heb je niet de hele dag mee gevuld. Een accu is nog steeds een vrij duur iets. Dat gaat vooral komen maar dat is toch wel moeilijk.
I: Dus zelfs in de wintermaanden kan je zelfs verwachten dat zonne energie dat het zelfs dan een soort van overload kan creeren.
G: Nee in de winterzon niet. Dan heb je nauwelijks aanbod. Dat is maar 10 - 20% vanwege de stand van de zon. En de dagen zijn korter ook. In de winter is dat niet zoveel ook vanwege die hoek levert het ook veel minder energie.
I: Dus het is ook als je naar een CO2 arme elektriciteitssysteem wil als ik dan naar zonne energie kijk dan moet je daar zoveel voor neerzetten om in de winter genoeg op te wekken.
G: En dan moet je ook veel opslaan. Dan zal je heel veel moeten opslaan
I: Dat is eigenlijk niet te doen.
G: Nee we zijn dus nu met een study bezig. Het potentieel aan Nederland als je echt alles optelt is 90 Gigawatt. Nou als je dat met 1000 uur heb je 90 Terrawatt uur. Dat is nog niet eens voldoende om de elektriciteitsvraag te dekken. De huidige elektriciteitsvraag. Dus daar red je het niet mee
I:"Zijn er nog andere duurzame bronnen volgens u waarvan u zegt dat kan nog echt een rol gaan spelen.
G: Import van waterstof. Ik kan me voorstellen dat er op een gegeven moment, of afgeleide producten, maar dat wij dus waterstof voor de elektriciteitsvraag waterstof gaan importeren.
I: Ik heb gelezen dat je met kleine aanpassingen waterstof in gascentrales.
G: Ja andere branders moeten er in.
I: Dat zijn niet de moeilijkste aanpassingen?
G: Nee en het is relatief goedkoop. Het is nog wel duur hoor. Dus voor 1 eenheid van 400MW betaal je ongeveer 40 miljoen om de branders aan te passen en geschikt te maken voor waterstof, maar dat valt mee als je kijkt naar de totale investeringskosten.
I: Waterstof is voor u wel een serieuze manier om overtollig energie op te slaan.
G: Ja. We ontkomen er volgens mij niet aan. Als we de chemische industrie in Nederland willen houden dan moeten we naar waterstof.
I: Dat hoorde ik van mijn begeleider. Er gaat wel veel energie bij verloren. Denkt u dat dat efficienter te maken is?
G: Nee je houdt altijd dat verlies. Maar besef goed dat als je vanuit duurzaam gaat moet je efficientie in een ander perspectief zien. Dat is gewoon meer plaatsen want het aanbod van zon en wind is enorm he. Dus als je dat bekijkt is het een oneindige brandstof. Efficientie is belangrijk want het bepaald voor een deel de prijs maar in die zin als je het naar elektriciteit omzet is het 2x 0,7 dus om het van elekctriciteit naar waterstof om te zetten is het 70% efficiency en dan weer terug als je het echt goed doet is het ook 70. Dan zit je op 49% en nog een keer transport verliezen een 10%. Dus ja dan zit je op een 35 - 40 wat je dan wint. Maar het gaat dus alles om de kostprijs. En als je nu ziet dat er in Saoedie Arabie vergunningen zijn afgegeven voor de bouw van een zonnepark die tegen 2 euro cent per KW uur elektriciteits produceert dan kan je ook aan opslag doen van waterstof.
I: Je kan natuurlijk die elektriciteit die met die panelen wordt opgewerkt dat vervoeren is niet echt een optie maar als je het omzet in een andere stof. Dus eigenlijk als wij een verdere verduurzaming willen van ons energiesysteem dan moeten we ook kijken naar energie omzetten in andere stoffen omdat daar grote mogelijkheden in zitten.

G: Ja
I: Ziet u nog mogelijkheden in andere opslagmethodes?
G: Nou ik denk dat alle opslagmethodes die gaan een kans maken. Dus ook batterijen misschien ook perslucht in Nederland en hydro waar je kan opslaan ga je dat ook doen. Er is voor alles ruimte dus denk van batterijen voor dag nacht en zo is er voor vele dingen ruimte.
I: Het belangrijkste is als het een economisch rendabel project wordt?
G: Ja
I: Dan wil ik graag aandacht geven aan de elektrische auto. Wordt dat volgens u een extra last of een verlichting voor het net omdat er ook vaak wordt gesproken over het concept V2G dat je het ook gebruikt als opslagmethode.
G: Ja het gaat overigens een beetje om hoe er geladen gaat worden. Voor het net is het belangrijk dat als iedereen gelijk gaat laden kan je het dan slim laden? Nou als je dat goed doet hoeft dat weinig problemen te geven he. Ik denk wat je wel moet beseffen is dat er wel concepten zijn voor de zelfrijdende auto en dat gaat een totaal ander concept geven. Dat we dus veel minder autos in het eigendom hebt maar ook het autobezit. Veel minder autos zullen rijden maar dat ze wel intesiever gebruikt worden. En het idee daarvan is dat er hele grote laatplaatsen voor de elektrische autos komen aan de grens van de stad komen. En dat die daarna naar de klant toe gaan enzo. Daar zou je dus het 110 -150 KV net wel moeten aanpassen om het vermogen dan naar die laadplaatsen te krijgen.
I: En de 110 - 150KV dan hebben we het over het transport alleen?
G: Het koppelnet is 220 - 380. Ja dit is dus eigenlijk van het koppelnet is het de tussenschakel naar het distributienet.
I: En u denkt dus als de zelfrijdende auto er komt dat die oplaadplekken voor de elektrische auto allemaal om de stad worden geregeld.
G: Ja ik weet niet hoe dat gaat maar daar zie ik nu dus concepten van. Dat er hele grote terreinen zijn op plekken in de stad waar er ruimte is waar ze dus centraal bij elkaar geladen worden, schoongemaakt worden en weer doorgaan.
I: En is dat ook een concept waar ze aan werken als het niet een zelfrijdende auto is maar gewoon de elektrische auto.
G: Nee maar dan zie je wel wel dus concepten van de laadinfrastuctuur wordt vaak gezien als een probleem.
I: Waarom?
G: 8 miljoen autos als je ze allemaal aan een laadpaal. Een hoop mensen staan in een straat dat is om bij ieder huis een laadpaal te maken. Je ziet dus wel. Want dit is gedeeld auto rijden maar zelfrijden komt er volgens mij zo aan. Dan zie je dus concepten waarbij een auto, dan heb je dus ook geen laadpalen meer maar dan heb je inductielussen in de grond. Waarbij dus auto op een gegeven moment als zn accu vol is. Die gaat naar een andere parkeerplek en dan komt een andere terug. Dus dan vind er een roulatie plaats. En je weet precies waar je auto staat met een app. Dat zie je dus ook aankomen. Maar opzich is voor ons zien we eigenlijk geen grote problemen vanuit het net met de auto. En je kan er behoorlijk deel van je overschotten in wegwerken. Als je de weersverwachtingen kent dan zeg je nu maximaal laden en als het slecht is en nu van het net af. Je krijgt er een stukje flexibiliteit door.
I: Het is natuurlijk ook dat het moment als het concept zou werken dat de elektrische auto ook gaat leveren op momenten dat er vaak stelt dat mensen thuis komen van hun werken het dagelijks ritueel dat mensen om 5 uur thuis komen dat die piekbelasting heel erg is. Op dat moment is de elektrische auto aangesloten zou je normaal zeggen. Daarom vroeg ik

ook of de vraag naar de elektriciteit maar op de piekbelasting momenten is het vaak juist aangesloten op het net om die.
G: Ja
I: U denkt geen grote problemen?
G: Nee
I: De grootste kans is als het zelfrijdende autos worden om steden heen op te laden. Op grote centrale punten. 8 miljoen laadpalen dat is gewoon niet te doen.
G: Nee. Maar dat hoeft ook niet. Als je straks de accuconcepten. Ja nu 500 -600 maar dat gaat wel naar 800 - 1000 waarschijnlijk. Een auto rijdt 15000 kilometer per jaar en dan heb je 15 tankbeurten eigenlijk nodig. Maar je zult hem waarschijnlijk niet helemaal leeg willen hebben dus met een 20 -25 keer tanken he. Dus dat gedeelt door 52 weken. Eens per twee weken ofzo. Dus dat moet gewoon kunnen.
I: Zijn die batterijen van autos al?
G: Nee dat nog niet maar Tesla levert alweer er zijn al autoconcepten die halen een actieradius van 500 kilometer.
I: Dat is meer dan een benzine auto.
G: Een gewone auto kan wel 700 - 800 kilometer. Maar goed met 800 - 1000 kilometer actieradius.
I:Die radius daar heb ik ook wel het één en ander over gelezen dat dat ook de elektrische auto mensen nog weerhoudt om aan te schaffen dat die radius want dat gaat hoogstwaarschijnlijk wel opgelost worden.
G: Ja
I: En u verwacht ook dat het oplaadnetwerk zo ver ontwikkeld is dat je ook wel net als bijvoorbeeld met een bezine auto wel overal kan komen.
G: Ook met punten voor snelladen ja.
I: Shell was daar volgens mij ook mee bezig. Die hadden een bedrijf opgekocht New Motion. Verwacht dat zij ook aan de snelwegen.
G: Nee dat waren 100 000 laadpalen. Want het andere is het E-Net wat langs te snelwegen staat met snelladen. Maar dat is de gewone laadpaal in de straat van Shell.
I: Voor de toekomst. Waar denkt waar de grootste uitdagingen liggen voor TenneT. Wat is voor jullie het moeilijkste in de transitie.
G: Voor ons is het moeilijkste de onzekerheden van de overheid. Een onduidelijk energiebeleid. Wij moeten voor investeringen doen. Het is zo dat planologisch dat is één ding waarmee we te maken hebben. Het aanleggen van hoogspanningsverbindingen in Nederland, wij zijn nu nog met één cyclus bezig maar dat wordt haast onmogelijk he planologisch gezien.
I: Heb je het dan over bestemmingsplannen?
G: Ja ruimte vinden. Dan zullen we ook ondergronds moeten. Maar ook dat. De mogelijkheden zijn beperkt. Daar moeten we goed naar kijken. Dat moet ook beseft worden. Dat wij niet onbeperkt door kunnen bouwen.
I: Dus eigenlijk wat u zegt is dat het huidige net wat er ligt daar moeten we het eigenlijk ongeveer mee doen. Er zijn nog wel een paar mogelijkheden
G: Ja vanaf de Eemshaven langs Groningen, stad Groningen naar de ring toe. Naar Ems. Dat is nog één groot project. In Zeeland van middelburg naar de centrale van Tilburg. Maar straks dan kunnen we nog offshore wind maar dan kunnen we het vermogen niet meer transporteren.
I: En denkt u dat dat een soort van rem gaat hebben op de transitie om naar een echt CO2 arm systeem te gaan?
G: Dat is dus als je vanuit een totaal energie perspectief gaat kijken dan hoeft dat niet.

Want dan is er gewoon heel veel. Als je dat slim kan regelen en we zouden dus vraag op de kust en zelfs op de zee als je zegt als we naar waterstof moeten gaan we dat op zee doen gelijk en dan gaan we dat via bestaande gasnet van GasUnie naar de kust brengen. Of particuliere bedrijven, zij hebben ook een eigen aansluiting. Maar dan het hoeft niet. Maar dan ligt het niet bij ons maar bij anderen. Daarom een goed overheidsbeleid die een duidelijk perspectief neerzet zou ons heel hard helpen.
I: Verwacht u dat dat met het nieuwe kabinet gaat komen. Het is wel iets groener ingericht denk ik.
G: Ja dat hopen we en dat wordt door iedereen aangegeven. Dat wordt ook door de industrie gezegd. We hebben nu een goed lange termijn beleid nodig om hierop te kunnen anticiperen.
I:Concrete projecten: Welke concrete projecten zijn jullie nu mee bezig of gaan er binnenkort komen om de transitie in gang te helpen?
G: Wij gaan alle windparken op zee aansluiten. Wij zijn de netbeheerder op zee dus alle ontwikkelingen op zee gaan via ons. Dat is onze doelstelling.
I: Dat is nu datgene waar jullie groots op inzetten voor de transitie?
G: Ja waar Nederland ook groot op inzet. Waar de overheid groot op inzet. Wij volgen gewoon wat de overheid zegt ja.
I: Dus wat ik dan als decentrale concepten voorbij zie komen, de buurtbatterij en.
G: Dat is niet voor ons.
I: U zegt ook dat dat niet iets is waarmee je de transitie kan bewerkstelligen? Is dat een soort van een extra toevoeging wat helpt?
G: Ja alle kleine beetjes helpen. Als 8 miljoen huishoudens een batterijpakket neerzetten ja dan helpt het ook weer he. Maar het is niet de grote klapper die voor ons belangrijk zijn. Dus puur vanuit TenneT geredeneerd
I: En dat de opslag dat wil je het liefst zo centraal mogelijk doen. Omdat je?
G: Nou waarmee je zit als je lange duur opslag wilt hebben, seizoensopslag, dan heb je weinig mogelijkheden in Nederland. Dan moet je dus wordt gezegd het opslaan van elektronen moet je omzetten in moleculen. In een chemische stof omzetten en kijk je dan wat je met elektriciteit kan doen dan lijkt waterstof uit water lijkt ook een optie te zijn.
I: CO2 opslag dat zie je ook steeds meer komen.
G: Kabinet zet er zwaar op in he. Chemische industrie 18 megaton CO2 opslag.
I: Wat gaat dat betekenen voor ons energie systeem. Ik zie aan de ene kant dat het ook meer kansen creert voor de kolen en gas centrales om langer te blijven lopen. Omdat je de CO2 opvangt. Je gaat dus wel doen aan CO2 arme energiesysteem maar.
G: Het kabinet heeft besloten dat alle kolencentrales voor 2030 dicht moeten zijn. Dat is door de overheid besloten.
I: Heeft u daar vertrouwen in?
G: Ja als je er betaalt voor wel. En er komt een belasting op CO2 van 45 euro per ton. Dus dat maakt die centrales ook alweer een stuk onaantrekkelijker. De subisidies op bio massa worden afgeschaft. Het wordt wel
I: Maar die kosten op CO2 wat u zegt. Als je dat afvangt en opslaat?
G: Nee dat red je niet voor 45 euro per ton. Dan zit je nog op 70 - 80 euro per ton. Van kolencentrales. He want dan moet je end of pipe, rookgas moet je reinigen en dat is nog duurder.
I: En het is natuurlijk ook niet dat je natuurlijk want volgens mij willen ze het in gasvelden opslaan. Het is natuurlijk niet dat daar lege holtes zitten waar je het gewoon in kan doen. Zal waarschijnlijk onder hoge druk.
G: Ja dat gaat dus in lege gasvelden. Dat lijkt de optie voor CO2 te worden.

I: Dat is zoals u het nu zegt. Als je kijkt naar de kosten van CO2 per ton is het uistoten is het uistoten goedkoper dan het opslaan.
G: Ja ook met die 45 euro per ton is het nog luceratiever dan opslaan.
I: Ik heb wel iets gelezen dat ze bij de EU de kosten van CO2 omhoog willen doen.
G: Ja maar dat is het ETS het european trading scheme, maar ja dat vliegt nog niet. Maar dan spreek je het ook in Europees verband af.
I: Denkt u dat die opslag waar ze het over hebben dat dat ook anticiperen is op de toekomst. Dat ze verwachten dat de kosten van CO2 uitstoten omhoog gaat?
G: Ik weet dat niet. Ik weet niet precies wat de motieven zijn geweest om hiervoor te kiezen. Want het staat natuurlijk verduurzaming wel in de weg. Als je hiervoor kost. Partijen kunnen maar één keer hun geld uitgeven. Dus als afvangen gaan ze niet nog een keer verduurzamen.
I: Nee het is of de opslag met de kolen en gascentrales of de windmolen heel kort gezegd
G: Nee de chemische industrie moet gaan opslaan. Die mensen hebben geen onbeperkt budget en CO2 afvangen is een dure optie. Dus als ze moeten investeren dan ga je zo 15 - 25 jaar daarmee doen.
I: Moeten er verder nog aanpassingen aan het net worden gemaakt om duurzaamheid verder te integreren. Naast de genoemde aanpassingen.
G: Er zijn allemaal specifieke kenmerken van elektriciteit waaraan gedacht wordt. Nu draaien de elektriciteitscentrales gigantisch blokken staal rond. En dat geeft een massatraagheid dus iedere slingering in frequentie worden wel grotendeels opgevangen. En allemaal speciale eigenschappen van elektriciteit vraagt dat er extra investeringen nodig zijn om dat op te vangen.
I: Is er nog iets wat we op dit moment hebben gemist maar wat wel belangrijk gaat worden voor ons energiesysteem. Als dat er komt of niet komt dat kan echt een gamechanger worden.
G: Dat is toch misschien de brandstofcel. En dat die dan in de huizen toegepast gaat worden voor de verwarming. Dus een deel van de huizen zal elektrisch gaan verwarmen. Een groot deel oudere huizen die zullen toch. Dat gaat heel moeilijk worden om dat all elektric te maken. Als daar een brandstofcel komt zou dat ook behoorlijke elektriciteitscapaciteit geven zodat je ook in de winter. Want als we waterstof hebben moet je in de winter voor een beperkt aantal uren een centrale beschikbaar hebben om elektriciteit te maken. Nou als je dat decentraal via brandstofcellen kan doen dan zou dat gigantisch helpen. Dus dat zou vanuit het systeem gezien zou dat een behoorlijke inpassing zijn.
I: En dat helpt omdat het net op bepaalde momenten de capaciteit moeilijk aankan als je het allemaal centraal wil regelen.
G: Ja en dan heb je verbruik en productie ook diep in het net zitten. Dus dan kan je het op wijkniveau of stadsniveau uitsmeren.
I: Ja je hoeft niet alles door 1 lijntje te drukken.
G: Ja daar zit ik wel naar te kijken.
I: Waterstof als belangrijkste opslagmogelijkheid
G: Voor ons als TenneT ja
I: En op decentraal dan batterijen. En dan vooral de elektrische auto of
G: Nee ook gewoon de thuisbatterij, de powerwall van Tesla bijvoorbeeld maar dan goedkoper.
I: U ziet daar wel een betaalbaar alternatief?
G: Dat weet ik niet. Maar daar moet je ook niet alleen naar kijken. Kijk thuis concurreert een huishouden met een kwart per KW/h dus en ja als je dus. Hoe minder je uit het net haalt

dus dan wordt het wel ietsje eerder aantrekkelijk om een batterij neer te zetten omdat je dan gewoon de kosten van het net en alles uitspaart. Dus daar zou het wel kunnen.
I: Even kijken de belangrijkste opslagmethode hebben we besproken. Dat is waterstof
G: Ja
I: Als allerbelangrijkste project de Noordzee.
G: Aansluiting van de windparken op de Noordzee ten aanzien van duurzaamheid. Ja
I: Waar we het nog niet over hebben gehad zijn de windmolens op land. Verwacht u daar nog.
G: Je ziet dus nu al dat het moeilijk wordt. Dat we de 20-20 doelstellingen niet gehaald wordt. De 6 Gigawatt
I: De veenkolonien in Drenthe. Dat krijg je wel een beetje mee in Groningen. Dat grote park wat daar gebouwd zou worden dat dat ook op heel veel weerstand is gestuit.
G: Ja en dat is het algemene beeld. Het wordt dan wel wat later gehaald. Maar voor ons vanuit het net gezien dat gaat ook maar om een paar honderd megawat en dat is voor ons dan weer relatief klein.
I: Dat zet niet heel veel zoden aan de dijk?
G: Nee. Voor TenneT dan he. Maar voor de regionale netbeheerder is het enorm.
I: Is bijvoorbeeld de Veenkolonien daar waren jullie daarbij betrokken of hebben we het dan over regionale.
G: Hoe heet dat? Is dat bij Groningen daar beneden?
I:Ja
G: Ja daar zijn wij ook bij betrokken. Dat is een paar honderd megawatt.
I: Dan heb je het wel over het transportnet?
G: Ja het 110KV net.
I: Eigenlijk kan ik het zo zien dat de indivuele windmolens op het regionale net zijn aangesloten en de windparken..
G: Ja de windparken zijn vaak bij ons.
I:Projecten op korte termijn hebben we gehad. Projecten op lange termijn heeft u daar nog iets over te zeggen?
G: Nou dat is voor ons dan weer de aanleg van de NorthSea Powerhup dus dat grote bij de Doggersbank om daar heel veel wind te gaan opwekken. Om dat te bouwen moeten wij zorgen voor de aansluiting en afvoer.
I:Het is heel duidelijk waar je gaan inzet waarop jullie inzetten de volgende 20 jaar.
G: Ja
I: Ik heb nog een vraag. Dat staat misschien een beetje los hiervan. Wanneer vind u dat we een slim energienet kunnen spreken? Want dat concept wordt vaak genoemd heb je het dan over het kunnen opslaan van energie of heb je het dan over demand side management?
G: Ja demand side management. Daar zit een slimheid in. Dus als je daar zaken weet te regelen in eerste instantie.
I: Dan moet ik vooral denken aan de communicatie van de slimme meter met de flexibele energieprijzen en de slimme huishoudelijke apparaten die richting.
G: Ja
I: Ja dat waren mijn vragen. Heeft u nog iets waarvan u denkt dat moet nog genoemd worden.
G: Nee volgens mij niet.
I: Dan wil ik u heel hartelijk bedanken voor de tijd.

Appendix 5: Transcribed and coded interview Enexis

Transcriberen interview met Henk Schimmel van TenneT

0:00 (...) 15:40
I: Ik heb nog een vraagje met betrekking tot.. ik maak een onderscheid tussen decentraal en centraal. Dat doe ik op basis van de verschillende netten. Transportnet, koppelnet, regionaal en lokaal distributienet. Is dit ook die scheiding die jullie daar precies in maken?
G: Ja dat wel. Ik kan je misschien nog wel een documentje sturen dat wij ook met netbeheer Nederland en met verschillende partijen afgesproken hebben hoe we dat proces gingen. Onder andere ook dat we dus eerder gaan in plaats van dat zij vergunningen hebben en dat wij dan aan het werk gaan. Maar daar staat eigenlijk ook in. Tuurlijk decentraal maar bijvoorbeeld op de Noordzee dat is een centraal opwekking die daar is. Wat is dan decentraal? Ik bedoel is Drentse monden Oostermoer waar 150 of 180 MW komt is dat nu decentraal of centraal? Nou uiteindelijk kun je zeggen het is een decentrale opwekking maar het is wel een behoorlijk grote. Want op dit moment moeten wij alweer uitbreiden, we zijn nog bezig maar moeten misschien alweer uitbreiden omdat we ook heel veel zonneparken komen. Ook van een paar 100MW wat aangesloten wordt. Uiteindelijk zie je dat zo`n als je ziet van in zo`n gebied komt er wel meer is dan het gebied zelf nodig heeft. Dus eigenlijk wordt daar zoveel opgewekt en zijn er maar hele kleine zoals Gaselte, Stadskanaal of Hunze en Aa en dergelijke, dat zijn niet zulke hele grote gemeentes. Uiteindelijk doen zij dus voor Drenthe een gedeelte van hun energie, wat zij moeten hebben, als provincie wordt in Drentsemonden Oostermoer in dat gebied wordt het opgewekt. Ik noem dat wel decentraal. Ik vind centraal is meer centrales. Dus de Magnum centrale, gascentrale, kolencentrale, kerncentrale of bijvoorbeeld. Ik zie dat nu langzaam ook als je over 600/700/800. Dat is net zo groot als een centrale. Als je dat op de Noordzee zet dan vind ik dat ook decentraal.
I: U vergelijkt het eigenlijk met de opwekking van de grotere centrales in Nederland.
G: Ja
I: Is het zo dat in Drentse Monden/ Oostermoer wordt dat meteen op het regionale net aangesloten of gaat dat via het transportnet.
G: Drentse Monden/ Oostermoer wordt op bijna 4 stations aangesloten. Een gedeelte op Veendam, een gedeelte op Gaselte, een gedeelte op Stadskanaal en een gedeelte op Musselkanaal. Dat is ook een heel groot gebied en dat zijn gewoon HSM station (koppeling met TenneT). Ik kan je straks wel even een plaatje laten zien. Om eventjes te laten zien. Ik weet niet hoeveel kennis dat je al hebt.

18:50 (....) 20:50
G: Wij kunnen dan rechtstreeks grote zonneparken aansluiten alles boven de 6 MW. Maar hier gaat het ook naar een verdeelstation. Hier kun je ook een zonnepark aansluiten. Maar die worden dan weer op een lager niveau aangesloten.
I: Het is eigenlijk bij de windmolens
G: Die zijn allemaal op het hoofdstation.
I: En indivduele windmolens dan?
G: Individuele windmolens, als ze onder de 6MW zitten, dan worden ze aagesloten op het transport verdeelstation. En als het hele kleine windmolentjes zijn, onder de 1,75 MW dan worden ze zelf in het distributienet opgenomen. Dus daar zitten de verschillen.
G: Wat we dus doen, vroeger als het 5/6 MW was dan zeggen we je moet naar TenneT. Maar dat is tegenwoordig al niet meer zo groot. En nu zeggen wij heel vaak, wij gaan het met TenneT samen bekijken wat de laagst maatschappelijke kosten is. Wij kijken naar de laagste maatschappelijk kosten en het kan dus zijn, bij de Eemshaven gaan wij een nieuw station bouwen, want daar heb je één die heeft 40 MW de andere heeft 30MW de ander heeft 10MW enzovoort.
I: Dan heb je er nog een kolencentrale staan.
G: Ja maar goed uiteindelijk zitten die op het hoogspaningsnet. En daar hebben wij dus niks mee te maken maar wij maken dan een nieuw station en wij sluiten dus die zonneparken en windparken rechtstreeks aan op dit onderstation. Of op dit hoofdstation. En sommige als ze heel klein zijn of iets dergelijks, op een transport verdeelstation. En dan heb je hieronder, dit is het distributienet daar heb je kleine zonneparkjes of bij boeren die zo`n zonnepark, die hebben we nu heel veel van Friesland Campina, die allemaal die daken vol met zon leggen. Die hebben misschien wel 400 of 630 KvA. Als ze dat allemaal op die daken leggen. Die krijgen een apart stationetje. En daar wordt het op aangesloten. Die zitten dus in het distributienet. Alle zonnepanelen die bijvoorbeeld op je dak zitten, bijvoorbeeld thuis, die zitten hierop. Die worden op het laagspanningsnet aangesloten.
I: Dat zijn eigenlijk voor de normale buurten die zitten allemaal op het laagspanningsnet en als het daarboven zit dan moet het eerst worden omgevormd naar een lager voltage?
G: Ja of opgedaan
I: Kan dat ook?Ik heb gehoord dat ons omdat wij een heel erg centraal georienteerd net hebben van origine dat ons net vooral erop is gebouwd dat alles naar beneden stroomt en niet omhoog.
G: Elektriciteit kan alle kanten op. Dus dat maakt helemaal niks uit. Hoeven wij ook niks voor aan te passen. Een beetje beveiligingen maar ik heb denk ik een mooi plaatje voor jou van mijn collega die pas geleden... eventjes kijken.
I: Ik vind het wel interessant wat u zegt want ik ben er vanuit gegaan dat het probleem van een decentraal georrienteerd net is dat je dan op plekken opwekken dat je het daar niet kunt krijgen omdat het heel moeilijk is om weer de stroom naar boven te brengen.
G: Nee dat is het niet. Uiteindelijk is het.... 24:36 (..) 24:49
G: Maar nu zie je dat dit allemaal plaatsvindt. Dus elektriciteit, gas of biogas die worden hier decentraal opgewerkt en het is nu tweerichtingsverkeer. Het gaat op een gegeven moment of naar TenneT, soms naar GasUnie, als er heel veel biogas opgewekt wordt. Maar ook van centrales en grote windparken en eventueel interconnectors. Met Denemarken of Duitsland, dat zijn de grote verbindingen die TenneT heeft met het buitenland.
I: De COBRA kabel
G: Ja bijvoorbeeld die voeden ook in het systeem. Dus het gaat nu heen en weer. Dus het gaat alleen niet naar de centrale en de windmolens die zitten centraal. Maar het gaat dan via de interconnectors Nederland uit. Dus zo zie je op een gegeven moment. Dit is het hele

nieuwe systeem. En dat kan ook je moet natuurlijk wel op transformeren maar een transformator kan alle kanten op. Een transformator kan zeg maar. Ik noem maar wat van 110 kan die 10 of 20 Kv maken maar hij kan ook van 10 of 20 Kv 110 KV maken. Dan kan die ook van laagspanning kan die ook naar 420 volt gaan maar hij kan ook van 420 volt naar boven. Maar die zonnepanelen zitten meestal op een gelijkspanning. Dus die worden met converters omgezet in wissel. En die wissel die komt op een transformator en die transformator transformeert het weer op naar een hogere spanning. Dus als je behoefte hebt naar deze plaatjes dan kan ik die wel geven.
I: Het is zoals gezegd, mijn uitgangspunt was dat het moeilijk is om omhoog te krijgen maar het is wel goed om te horen dat het niet zo is.
G: Het enige is en dat is wel iets wat natuurlijk wel goed is om te vertellen. Dat als je heel veel decentrale opwekking hebt. Je moet het ongeveer vergelijken, elektriciteit kun je het beste vergelijken met water. Als je een hoosbui hebt dan loopt het over want die pijp is te dun. En dat gebeurt ook met spanning. Als je namelijk heel veel opwekt in een gebied dan loopt de spanning omhoog. Dat betekent dat de spanning te hoog wordt. Als het te hoog wordt dan zit er een beveiliging in dan gaan de converters uit. Dat betekent dat die zonnepanelen niet meer werken. Zijn niet kapot. Is de spanning weer lager dan werkt de converter weer maar mensen vinden dat niet zo mooi. Ik heb zonnepanelen en heb daarvoor geinvesteerd en nu kan ik het niet meer kwijt. Dan moeten wij een extra kabel leggen. Dus zo zit het. Dan doen we het net met water. Dan moet je een extra pijp neerleggen zodat het afgevoerd wordt. Nou dat is het eigelijk ook met elektriciteit. Nou dan zegt men ja als je heel veel opwekt dan krijg je het niet weg. Ja als het meer is dan er in de buurt verbruikt wordt. Want dat is het mooiste natuurlijk. Er wordt iets opgewekt en het wordt meteen gebruikt. Dan heb je minder transportverliezen enzovoort. En dan hoef je die ook niet in te kopen als Enexis.
I: Dan hoef je als je alles centraal zou willen opwekken dat dat eigenlijk niet mogelijk is omdat je dan alles op bepaalde momenten door een kleine kabel moet drukken.
G: Ja dat kan maar je kunt dat ook verzwaren. De andere kant is, wij verwachten dat eigenlijk bij de energietransitie zie je dat zonnepanelen en windparken decentraal gaat het makkelijkste. Er we moeten nog besparen. Dus we moeten veel meer isoleren. En we doen al heel veel met LED verlichting en energie zuinige, minder elektriciteit verbruiken. Maar we wekken nu wel veel meer op. Maar wij verwachten, en dat staat ook in de plannen van de overheid dat we elektrisch gaan rijden en als we elektrisch gaan rijden dan hebben we dat zelfde net nodig, dan hoeven we geen nieuw net aan te leggen maar dan hebben we hetzelfde net nodig die we nu uitbreiden voor de decentrale opwekking. Het afvoeren van elektriciteit van opwekkers. Die hebben we straks nodig voor onze elektrische auto`s. En heb je warmtepompen, die hebben ook elektriciteit nodig. Die halen warmte uit de lucht.
I: Een soort omgekeerde koelkast.
G: Helemaal. Of omgekeerde air conditioning. Die gebruiken elektriciteit. Als mensen dat gebruiken, dat is misschien wel 1 of 2 KiloWat. Op dit moment gingen wij van onze vroege netten uit dat die uitgelegd waren voor onder andere 1,5 kilowat per woning. Maar als die woning nu 1,5 KW doet plus nog elektrisch koken gaat, plus nog een warmtepomp en pa of ma komt thuis en die prikt ook nog een keer de elektrische auto in. Dat betekent gewoon dat dat huis 6/7 Kilowat doet. Dat betekent gewoon dat wij dat net vol moeten hebben. Maar als die ook zonnepanelen op het dak heeft kan die op een gegeven moment, alleen snachts werkt dat niet, maar overdag ook in die auto stoppen. Maar uiteindelijk kan die op een gegeven moment, dat net moet dan al uitgelegd worden voor die decentrale opwekking. Maar dat kunnen dan ook gebruiken voor die belasting. Dus wat dat betreft denk ik. Dat als TenneT alles op zee doet dan moeten wij nog meer hoogspanningsmasten vanuit zee door

het land trekken. Want uiteindelijk je kunt wel opwekken op zee maar dat zul je ook naar de klant toe moeten doen. Dus als de klanten meer naar elektriciteit gaat en meer naar gas zul je dat distributienet ook uit moeten leggen. Dus met andere woorden. Ik zie van decentrale opwekking en dat we daar investeren om bijvoorbeeld om ons net veel meer te verzwaren zie ik in principe. Dat moet toch gebeuren. Omdat wij toch minder met gas gaan doen dus het zal meer naar elektriciteit gaan.
I: Er moeten ook grote investeringen komen in het net.
G: Sowieso. Want dat is ook logisch want we gaan straks naar 100% duurzaam. En dat halen we niet meer uit gas. En gas heb je bijvoorbeeld 2000 kuub. Sommige hebben nog veel meer. Maar dat moet je bijna maal 10 doen. 9,8 ofzo. En dat is in elektriciteit de energie die gas is veel groter.
I: Dichtheid ofzo
G: Ja de energiewaarde dus met andere woorden. Als jij hetzelfde als die 2000 kuub en je wilt dat 100% elektriciteit maken dan moet je dus ongeveer 10 keer zoveel opwekken. Aan kilowat uur. Dus zo`n groot dak heb je niet. Of je moet in een kasteel wonen.
I: Hele grote boerderij hebben.
G: Ja dan wil het.
I: Dat verzwaren van het net wat u zei. Moet ik dat zien als het verzwaren of uitbreiden. Of beide?
G: Het is beide. Allereerst in laagspanning daar ligt overal wel een net. Dat zullen wij moeten verzwaren. Maar er zit ook wel heel veel capaciteit in het net. Ik heb pas geleden een collega van mij heeft dat bekeken. Meeste transformatoren dat zijn transformatoren voor 400/600 KvA en als je ziet als al die daken vol liggen. Alle daken kunnen ook niet vol want 1 zit op het noorden dat levert minder op. Je hebt Noord Zuid dan is het allebei niet gelijktijdig. Met andere woorden dan gaat die piek ook niet smiddags heel hoog worden maar die is meer uitgerekt. Smorgens begint het vroeg en s`avonds laat levert die nog terug. Maar als je dat bekijkt moeten wij hier en daar wat transformatoren neerzetten maar uiteindelijk zien wij dat niet als een groot probleem. Laagspanning moeten we hier en daar ook wat uitbreiden. Net wat ik zeg, wij verwachten dat er ook veel elektriciteit verbruikt gaat worden. Omdat mensen toch langzaam kiezen voor elektrisch koken of iets dergelijks.
I: En als je die opwekking in een CO2 arm systeem als je dat zou moeten verdelen onder de verschillende generatoren. De manier waarop je het kan genereren. Hoe ziet u dan de ideale verhouding? Moet er toch meer wind zijn of meer zonne energie?
G: Kijk ik verwacht nog wel dat er mogelijkheden zijn voor wind op land ondanks het nu met de eerste 6000MW erg moelijk gaat. Bij sommige gebieden. Wij zitten hier in de provincie Groningen. Groningen heeft nu voor wat zij moeten hebben. 855 MW volgens mij daar hebben ze nu vergunningen voor. Dat wordt ook gerealiseerd voor 20-20 en daarna zijn ze al bezig met die jaren er naar. Want die willen in 2035 ofzo willen ze al 60% duurzame energie hebben opgewekt. Dus uiteindelijk kijken zij nu ook waar zijn er nog mogelijkheden? En ik weet rond de stad. Tuurlijk ligt het wel gevoelig maar de stad wil al in 2035 energieneutraal zijn. Stad Groningen. Nou dan mogen ze nog een stapje harder want alleen maar met zonneparken kom je er in de stad niet. Nou heb je gelukkig dat ze nog Ten Boer erbij krijgen want die heeft nog eens een keertje extra grond. Maar de stad Groningen net als met de stad Assen, die hebben dusdanig weinig ommelanden. Dan moet je midden op de grote markt een windmolen van 200 -250 meter hoog neerzetten. Dat kan als je hem net boven de Martinitoren uittilt.
I: Dat wordt niet echt gewaardeerd denk ik.
G: Maar goed je hebt wel aangegeven dat je duurzaam wilt.
I: Het is wel een statement.

G: En het voordeel is tuurlijk wel dat de meeste energie in de stad gebruikt wordt. Door al die winkels.Kijk dat zou het dus niet worden maar uiteindelijk denk ik wel, ik merk het met Assen, met meerdere gemeentes, Hardenberg ben ik bij betrokken. Kijk Hardenberg is dan een plattelandsgemeente, die hebben nu ook windmolens maar die zeggen ook ja we gaan toch wel meer inzetten op windenergie dan op zonne energie want zij hebben heel veel landbouw. En zij willen die landbouw niet volleggen met zonnepanelen.
I: Dat neemt veel te veel ruimte in.
G: Ja die vinden dat teveel ruimte innemen en dat betekent gewoon dat concurreert bijvoorbeeld met landbouw en daarom zeggen zij nou wij zijn eerder voor windmolens want dat tikt veel harder aan.
I: Ja dat is en en in plaats van en of
G: Ja en ik denk dat volgende stap. Sommige die maken zich nu al zorgen over dat wij straks veels te veel elektriciteit opwekken. Veel te veel zon en dat er dan snachts geen elektriciteit is. Nou je moet dan als wij nog maar 4% hebben opgewekt op dit moment moeten we ons niet zorgen gaan maken over een probleem die er niet is. Laten we nu eerst zorgen dat we die 14 of 16% die we in 20/20 en 20/30 16%. Nou laten we dat eerst nu eens voor elkaar krijgen. En in die tussentijd zie je dat die ontwikkelingen doorgaan. Je hebt nu ook andere type batterijen. Nou elektrisch rijden kunnen we veel in stoppen. Als je daar een miljoen autos hebt en stel dat je 50% staan ergens te laden. En je zou die ergens eventjes extra laden 1 of 2 Kilowat extra. Dat betekent dat je een centrale aan en uit zet. En dat gaat heel snel. Daar hebben ze al proeven mee gedaan met Tesla`s. Zij kunnen straks ook dat gaat ook gebeuren, dat die auto`s ook terug kunnen leveren.
En ik verwacht ook. We zijn ook bezig met zoet zoutwater accu`s.
I: Is dat de blauwe energie bij de Afsluitdijk
G: Ja maar dat is puur opwekken. Maar wij zijn ook bezig en er zijn ook allerlei proeven al om zoet en zout water als opslagmechanisme te gebruiken. Dus als je dat doet dan kun je energie ook opslaan in water. Als je dat dan gedaan hebt. Die membramen zijn nog wel een beetje duur dat.
I: Dat is altijd aan het begin zo op een gegeven moment zie je dat ze het efficienter kunnen maken als ze het op grote schaal maken.
G: Ja en op een gegeven moment, op dit moment zeggen ze iedereen krijgt een eigen accu in huis. Nou dat kan. Ik heb ook al begrepen wij zijn ergens in Overijssel bezig waar we wel iets met zoet en zout water een accu in de huizen neerzetten. Maar die moeten dus veel goedkoper worden. Op dit moment zo`n Tesla accu die kost ongeveer 10.000 euro. Ja 10.000 euro. Op dit moment kun je het gratis op het net kwijt. Dan heeft het weinig nut om het op te slaan. Wij doen daar ook proeven mee. Mijn energiemoment is dat. En dat werkt best wel.
I: Op lange termijn gaat dat er wel komen de accu thuis.
G: Ja maar als ik een auto voor de deur heb dan is het toch goedkoper om de auto in te zetten.
I: Het is wel een risico om alleen te gokken op auto`s denk ik. Want je weet niet wanneer ze zijn aangesloten op het net of wanneer niet. Of is dat.
G: Nou kijk op een gegeven moment is zoiets van je kunt. Kijk als ze aangesloten zijn de meeste mensen weten dat is wel te zien dat ze aangesloten zijn. Sommige hebben ook contracten. Bijvoorbeeld ik ken collega`s die pluggen dat s`avonds in. Die zeggen ik wil dat ding 60% vol hebben. Dan kan ik naar mn ouders als er iets is. Maar die laatste 40% mag je zelf aangeven wanneer je dat gebruikt. Als het maar om 7 uur sochtends maar 100% vol is.
I: En als je dat keer een miljoen doet.
G: Dan heb je een hele buffer staan. En ik heb zo`n app. Ik heb ook een elektrische auto

besteld maar daar moet ik een jaar op wachten. Die is volgend jaar.
I: Een Tesla ook.
G: Nee geen Tesla. Dat is voor mij mocht dat niet. Maar ik heb een Opel ampera. Die heeft ook een accu net zo groot als een Tesla.
I: Genoeg opslagcapaciteit.
G: Ja is alleen een stuk goedkoper
I: Ik wil nog even terug over wind en zon die verdeling. U zei bijvoorbeeld dat die gemeente in Overijssel, Hardenberg. U zei ze hebben daar liever een voorkeur voor windmolens omdat ze daar aan landbouw doen is dat een algemene trend dat er veel plattelandsgemeentes voorkeur geven aan windenergie?
G: Nee dat is niet zo.
I: Dat kan echt verschillen per gemeente?
G: Ja bijvoorbeeld Drentse Monden Oostermoer en alles wat daar in de buurt zit. Ja die zijn heel erg tegen wind. Dus die gaan eigenlijk voor zonne energie. En ze krijgen wind omdat ze dat verplicht zijn. Maar uiteindelijk wij hebben pas geleden een keer een spel van EnTranCe gedaan ik weet niet of je dat kent?
I: Ja dat is bij het Zernike daar van de Hanze.
G: Van de Hanze ja. En daar hebben we dus met zulke dorpen gedaan. Of het Loppersum is of andere en dan gaan ze kijken nou zoveel energie verbruiken wij en nu moeten wij kijken wat wij doen. Dan beginnen ze te schuiven en dan moet er heel veel akkerbouw moet voor biomassa. Dan denken ze wij hebben hele dure aardappelen telen wij hier dat kunnen we niet al die aardappelen. Met andere woorden dan kijken ze naar zon. En doen ze ook wat zon inzetten. Maar uiteindelijk zeggen ze nu wordt de zon tussen hele dorpen worden belegd met zon. En dan hebben we akkerbouw en dat willen we ook niet. En dan kijken ze als ik een windmolentje hier zet eerst van die hele kleine windmolens, die tikken ook niet aan. En dan pakken ze toch zo`n grote molen. Eigenlijk als je dan één molen waar we hem neerzetten. Uiteindelijk zie ik dat sommigen toch ook wel kijken of er wat mogelijk is voor een dorpsmolen of iets dergelijks. Dat daar best wel animo voor is. En wat wij dus willen is ook nog wind en zon koppelen op dezelfde aansluiting. Dus het is bijna nooit gelijk en we moeten nooit ons net uitleggen voor die piek. Wij moeten ook gewoon zeggen als die pieken er zijn en we hebben daar last van dan moeten we die pieken weggooien.
I: Dan heb je het meer over het managen van de vraagkant?
G: Ja het balanceren. Maar ook net wat TenneT ook doet met zijn connectors naar het buitenland. Die zeggen ook dit zijn de capaciteit van de connectors dan is er onderhoud dus ik heb beperkte mogelijkheden. En daardoor wordt het allemaal in het energiesysteem met een algoritme bekeken. Wie heeft aanbod van welke centrales tegen welke prijs en uiteindelijk wordt het op de markt bepaald wie mag leveren aan wie. Voor welke bedragen en daar zit ook de capaciteit van het net bij in. Nou op dit moment geld dat alleen voor TenneT niet voor regionale distributiebedrijven. Het zou best wel in de toekomst goed zijn dat zoiets niet alleen bij TenneT ligt maar dat wij ook voor onze regionale distributienetten ook kunnen kijken hoe kunnen wij dat balanceren van de vraag. En kijken op zo`n goed mogelijke manier inzetten. Daarnaast heb ik nog een gesprek gehad met TenneT en de gemeente Emmen. Uiteindelijk denk ik gewoon dat er geld te verdienen is op flexibiliteit. Een bedrijf kan zich flexibel inzetten.Er is al een bedrijf in Delfzijl die dat al jaren doet. Dus die kan gewoon heel makkelijk zijn proces gewoon stoppen. En gewoon zeggen nou op dit moment is de elektriciteitsprijs duur en dan ga ik niks doen.
I: De verwarming gaat dan langzamer draaien.
G: Ja ze hebben dan een bepaald productieproces dat ze dat ding gewoon kunnen stoppen en dan is elektriciteit eigenlijk goedkoop of er is zelfs teveel elektriciteit. En ze helpen

eigenlijk het probleem op te lossen. Nou dan zetten ze alles volop aan en dan gebruiken ze bijna alle energie die ze nodig hebben. Bijvoorbeeld heel veel koelinstallaties bij boeren zijn we al mee bezig. Smart farmer grid. Waar wij ook bij betrokken zijn om te kijken of je de melk kunt koelen op momenten dat er veel aanbod is. Of koelhuizen, als je nou 1 of 2 meer koelt op moment dat er veel aanbod is kun je dan niet uit de piek van 6 uur zijn als er veel vraag is en aanbod voor elektriciteit.
I: Moet ik dan ook denken aan volledig flexibele energieprijzen.
G: Ja dat gaat ook gebeuren. Kijk energieprijzen worden niet door ons bepaald maar dat wordt door energiemaatschappijen bepaald en die kopen in en die kopen ook afhankelijk van het uur betaal je een andere prijs voor elektriciteit.
I: Dat wordt nog niet doorberekend aan de klant?
G: Ja dat zou kunnen we hebben allemaal slimme meters. Dus eigenlijk zo straks iedereen kunnen zeggen ik wil een flexibel contract en ik zorg zelf wel met een managementsysteem in mn huis dat ik de wasmachine aandoe als de prijs laag is. Dus met andere woorden op die manier zou het best wel kunnen. Dat is alleen de elektriciteitsprijs maar de elektriciteitsprijs is ook nog opgebouwd uit onder andere netwerktarieven. Of we hebben nu nog een vast tarief voor kleingebruikers. Een capaciteitstarief dus iedereen betaalt ook evenveel.
I: Dus geen dag of nacht tarief.
G: Ja dat wel maar dat is voor de elektriciteitsprijs maar niet voor transport. Dus met andere woorden voor het leveren wel maar niet voor de transport. En wij als netwerkbedrijf moeten wij ook naar flexibele tarieven. Dat we zeggen er is ook te weinig capaciteit op het net en als je op dat moment niet gebruikt maakt van het net of juist wel als je ons kunt helpen door wel veel te gebruiken. Dan zou je daar op een gegeven moment een ander tarief voor moeten neerleggen. Daar hebben we wel proeven mee gedaan. Mijnenergiemoment. Moet je maar eens een keer googlen. Dan kun je daar wel zien dat we daar proeven mee doen. Maar goed daar hebben we wel proeven mee gedaan. Ik weet niet of er veel informatie op staat. Maar dat zijn wel momenten. Maar het punt is dat mag nog niet. Wij mochten dat doen omdat het een pilot is.
I: In Hogekerk was dat?
G: Ja Hogekerk heeft ook zo`n soort proef gedaan. We hebben er nu ook één gedaan met Teslabatterijen. En uiteindelijk zie je wel dat op een gegeven moment dat dat beinvloedbaar is.
I: Denkt u ook als je echt naar een CO2 arm energiesysteem wil waarin je windmolens en zonne energie als die gaan opwekken dat het noodzakelijk is om die vraagkant te sturen omdat de aanbod kant ook moeilijk te regelen is.
G: Ja ik denk wel dat dat. Kijk het is voor de maatschappij het goedkoopste want dan hoef je grote dure investeringen niet te doen. Plus stel dat je op het moment dat je veel verbruikt of veel opwekt en andere moment minder. En hoe meer dat je dat in het systeem af kunt vlakken hoe beter dat is. Je hoeft er ook minder windmolens en zonneparken neer te zetten.
I: Vooral om de piekvraag meer te spreiden overdag?
G: Ja op momenten kijk overdag wordt er heel veel zon opgewekt. Eigenlijk moet je dan zorgen dat je dan gewoon je wasmachines aanzet. Je bent dan op je werk.
I: Huis misschien verwarmen voordat je thuiskomt.
G: Ja bijvoorbeeld warmtepompen dat zou kunnen. Je zou ook op een gegeven moment warmte kunnen maken van de zon of iets dergelijks waar je dus op een gegeven moment buffert. Je zou het ook nog in de grond op kunnen slaan. Je kunt ook wel één of ander vat onder je huis neer leggen waar je warmte opslaat en wat je dus s`avonds weer gebruikt.

Als er geen zon schijnt. Op een gegeven moment zijn er wel momenten waarop je die opslag niet altijd direct in accu`s hoeft te hebben. Het kan ook gewoon in verschillende verbruik.
I: Ik had nog een vraag met betrekking tot een soort van jaarprofiel voor zonne energie hoe dat wordt opgewekt. Dan zie je vaak in de zomer is een piek en wind energie is dan meer in de winter vaak een kleinere piek. Denkt dat u dat deze verschillen belangrijk zijn voor de verdeling van de opwekking hoe dat wordt verdeeld in de toekomst. Wat ik daarmee bedoel dat de wind energie, het jaarlijkse profiel, wat meer aansluit bij de vraagkant van Nederland in de winter en zomer.
G: Dat is ook zo en vooral nu de windmolens veel en veel groter worden zie je dat op een gegeven moment ook. Kijk vroeger had je windmolens die hadden 1500 vollast uren. Een vollast uur is dan gewoon stel je op een windmolen van 3 MW. Dan zou je op een gegeven moment als je dat bekijkt naar het totale verbruik dan is het die 3MW maal die 1500 uur. Maar windmolens die al 2000 en ze gaan nu al richting de 3000. Dat komt gewoon omdat ze veel hoger worden.
I: Ik heb al gezien dat ze richting de 8 of 9 MW.
G: Ja als ze heel erg hoog worden dan wordt het terugleveren al veel langer. Ik heb hier ook wel een plaatje van hoe het nu is met zon en wind. Ik pas geleden een presentatie ergens gegeven. Maar dat is iets van 53:40 (.....). 54:12
I: Dat de wind veel hogere pieken heeft dan de zon.
G: Nou dat hangt er vanaf want dit heeft ook meer vermogen. Wind is 95,5 wat zijn moeten realiseren. Zon is 70 MW piek. In geval hebben ze dat. Nou dit gaat over decentrale opwekking. Die onderste dat is maar heel weinig. Dat is ten opzichte van de rest. Je ziet gewoon je hebt ook pieken in de zomer. Kijken sommige denken van wind. Sommige denken in de zomer heb je alleen maar zon en geen wind. Je hebt ook wind. En soms ook hele grote pieken. Want deze pieken zijn wel iets lager dan in de winter maar deze zijn ook nog behoorlijk hoog. Dus als je die zon erbij optelt dan heb je uitschieters.
I: Het is hoe ik het mij voostelde dat wind wat makkelijker in te schatten was maar eigenlijk als ik het zo zie is de zon daar zit veel meer.
G: Ja maar wind is ook. We hebben wel eens een periode gaat of nog langer er geen wind was. Maar ook dat er geen zon was. Allebei. Dus hebben we dat wel eens gehad pas geleden. Dat het helemaal. En daarom moet je die systemen dat je die koppelt. Zelf niet alleen met Engeland of Denemarken maar dat je het ook koppelt met het Oostblok, meer die kant op. Of met Spanje.
I: Eigenlijk het idee is hoe groter het elektriciteitsnet wordt hoe betrouwbaarder om. Als er hier nog wordt opgewekt dan heb je in Spanje wel ergens.
G: Stel dat je hier een lager drukgebied hebt. Het is bewolkt en mistig en het waait niet. Dan is het ook vaak in Duitsland en een groter gebied. Dat betekent dat in een heel groot gebied niet opgewekt wordt. Dus uiteindelijk moet je dan die koppeling hebben met andere gebieden.
I: Lage druk betekent vaak dat er weinig wind is en er ook slecht weer is.
G: Ja. En zo gaat de uitwisseling met TenneT. Dit is de bovengrens wat er teruggeleverd wordt. En dit is eronder. Je ziet dat het heel erg heen en weer gaat.
I: Dit is julie teruglevering?
G: Ja ik heb dit nu even gedaan. Soms is er belasting dus uiteindelijk zie je gewoon dat er dus. Het vliegt alle kanten op zeg maar. Dus met andere woorden dat kan ook in de Travolt. Dat is geen enkel probleem.
I: U zegt er vindt al heel veel uitwisseling plaats in het net erboven.
G: Ja. Net zoals in Delfzijl en Eemshaven zijn er momenten dat onze transformatoren altijd

terugleveren aan TenneT. Dus zo zie je hoe het in elkaar zit. Maar goed het is volgens mij wat wij gedaan hebben. In Maart mag dat je meerdere leveranciers op één aansluiting hebt dus dat je wind en zon koppelt. Zodat je ook de bestaande aansluiting zo effectief mogelijk maakt. Dan hoef je maar één aansluiting te maken. Plus dat je zon en wind erop dat en dat je zegt soms is zon aanwezig maar zon is alleen maar aanwezig met zn piek tussen 11 uur en 2 uur. Dus met andere woorden als je tussen 11 en 2 de windmolens terugdraait afhankelijk van hoeveel er zon is en wind is en daarna kan wind ook weer volledig beginnen want dan gaat zon naar beneden. En tegen een uur of 5-6-7 uur dan is de zon bijna helemaal weg. Dan is de zon nog maar een paar procent.
I: U zegt dat als je probeert clustert van wind en zonne energie te maken en die met elkaar laten communiceren over hoeveel opwekking en dat dat clustert dat zelf regelt hoe ze dat onderling.
G: Ja kijk achter dat cluster dat doen wij niet. Daar zitten initiatiefnemers. De eigenaar van die wind en zonneparken. En die kijken op de markt wat is de prijs en wat komt er aan. Dus die krijgen misschien een week van tevoren dan en dan wordt zoveel zon en wind verwacht en op een gegeven moment een dag van tevoren moeten ze aangeven hoeveel zij denken aan het systeem te leveren. Leveren ze minder aan het systeem dan ze gezegd hebben dan moeten ze zelfs onbalans betalen. Er dat zijn hele grote bedragen. Dus ze schatten het ook wel eens wat lager in en uiteindelijk draaien ze ook wel eens windmolens terug. Want het is ook onbalans als je veel te veel levert aan het systeem als het systeem er niet om vraagt. Dan gaat de frequentie in Nederland omhoog. Ik weet niet of je er wel eens van gehoord hebt.
I: De heilige 50 Hertz?
G: Ja als je die op een gegeven moment omhoog of omlaag doet dan grijpt TenneT in. Dan kan centraal afgeregeld worden. Maar op dit moment kan TenneT ook anderen vragen om een bijdrage te leveren in de onbalans.
I: In Europa heb je het dan over?
G: Ja maar ook in Nederland. Het is wel gekoppeld maar uiteindelijk gaan zij ook voor het Nederlandse deel. Er zit ook een stuk in Duitsland. Daar hebben ze ook verantwoordelijkheid over. Maar uiteindelijk moet je de frequentie op die 50 houden.
I: Om het duidelijk te hebben. Ook de Nederlandse regionale netbeheerders hebben belang bij een betere internationale connectie omdat ze dan hun stroom ook daar naartoe zouden kunnen verkopen.
G: Nou verkopen niet. Ik denk dat dat gewoon voor het totale systeem beter is. Kijk wij moeten dat naar TenneT doen maar het is ook handig dat TenneT het af kan voeren. Dus uiteindelijk is het voor het totale nederlandse en europese systeem wenselijk dat er goede connecties komen met landen die ook een bijdrage kunnen leveren aan het systeem. Zo hebben wij dus pas geleden een gesprek gehad. Dan willen ze een connectie ergens maken met een gebied die eigenlijk ook al een probleem is. Dan moet je denken, je kunt twee problemen bij elkaar neerzetten en dan kun je het ook oplossen. Maar je kunt soms ook het probleem alleen maar groter maken. Dus uiteindelijk kun je zeggen. Waarom doen we naar Denemarken? Waarom?
I: Heel veel wind energie?
G: Nee veel water. Daar worden op een gegeven moment..
I: Is dat in Nederland ook zo?
G: Ja voor die NOR kabel Noorwegen ja. Denemarken heeft weer andere dingen. Oja dat klopt. De NOR kabel is dat. Maar uiteindelijk zijn er wel weer sommige systemen voor wind of niet. De NOR kabel is inderdaad met veel water.
I: Denemarken is nog vlakker dan Nederland. Ik heb dat ook wel eens opgezocht. Die

COBRA kabel naar Denemarken. Hebben ze daar dan ook wateropslag? Toen zag ik 170 meter ofzo is het hoogste punt.
G: Ja dat is ook weinig.
I: Maar het is wel belangrijk dat het internationaal verbonden is voor de stabiliteit.
G: Klopt
I: Eens kijken we hebben al heel veel doorgelopen. Even kort voor zon. Zowel voor zonneparken als individuele panelen dat gaat beide gebeuren. Of dat is voor de hand liggend?
G: Ja want ik zie zelf. Ik verwacht zelf. Volgens mij zijn ze op de universiteit ook wel bezig met zonnepanelen.
I: De energy academy heb je
G: Onder andere. Dus die zijn ook ontwikkelaar van zonnepanelen en die worden aller hoe dunner en goedkoper. Straks is de grootste prijs die je moet betalen de omvormer en dat je ze erop legt. Maar uiteindelijk zie je dan krijg je zo gewoon in dunne film. Maar ook in verf. Je kunt ze in de gekste dingen kun je zonnepanelen van maken.
I: Ja je hebt al zonnepanelen die er al uit zien als dakpannen inderdaad.
G: Ja dat heb e ook
I: De vorm niet echt maar het lijkt niet op een traditioneel zonnepaneel.
G: Het lijkt echt op een echte pan
I: Verschillende kleuren
G: Je kunt ook verschillende kleuren krijgen. Ook bijna doorzichtig. Ik zag een artikel vandaag in Duitsland hadden ze niet een proef gedaan om 4 meter hoog boven een akkerland zonnepanelen neer te zetten die ook doorzichtig waren. Die gingen dus tweezijdig energie opwekken. En de opbrengst van sommige was wel wat lager. Dan bedoel ik de opleg van bijvoorbeeld aardappels of mais. Dat was wel 10 of 15% lager las ik. Maar de opbrengst voor die zonnepanelen omdat ze aan twee kanten konden was de opbrengst veel meer.
I: De totale opbrengst van het land dat was hoger.
G: Ja dat was veel meer. Elektriciteit wordt veel meer opgewekt dan zonnepanelen gewoon op het land. Omdat ze ook dubbelzijdig waren. Maar ze waren wat transparanter maar wel dubbelzijdig. En de opbrengst daaronder met bijvoorbeeld graan en andere dat was lager maar uiteindelijk was het..
I: Uiteindelijk hoeft het bij landbouw niet eens of landbouw of zonnepanelen zijn maar het kan ook gewoon beide.
G: Daar zijn ze nu mee bezig.
I: Dan lijkt het bijna vanaf de snelweg als kassen ofzo.
G: Jaa. Maar goed zie je dus dat die panelen worden aller hoe goedkoper. Dan ga je het ook van nemen.. we kunnen nu als huishoudens salderen of weet ik wat. Maar uiteindelijk wil men dat eraf hebben. Maar daarvoor komt in dat je dus een vergoeding krijgt voor wat je teruglevert. Als je dat dus krijgt dan krijg je ook dat mensen gaan maximaliseren. Vroeger kreeg ik wat ik teruglever helemaal niks voor ik krijg er straks wel 6 of 7 cent. Dus dan ga ik maximaal mn dak volleggen. Dat zie je ook bij de nieuwbouwwoningen al. Jammer genoeg niet bij iedereen
I: Ja ik woon ten Noorden van. Zegt u paddepoel iets?
G: Ja
I: Ik woon in een nieuwbouwflat en daar zijn ze nu voor mij hebben ze eerst alles afgebroken en daar zijn ze nu een x aantal rijen koopwoningen aan het bouwen. En ik kijk aan tegen daken waar 1 of 2 zonnepanelen op liggen. Als je een rijtje verder kijkt dan zie je er al wat meer. Nog een rijtje verder dat zit bijna helemaal vol en bij de 4 zit het al helemaal

vol. Je ziet wel hoe snel dat gaat met wat u zegt, helemaal vol leggen.
G: Ja dat zie je ook met 0 op de meter woningen. Wat ze maken van huurwoningen. Dan moet het dak toch ook geissoleerd worden. En dan zetten ze er gewoon helemaal een nieuw dak op en dat is dan alleen maar zonnepanelen. Dan denk ik waar het veel meer op gaat, wij zijn als Enexis betrokken bij Rijkswaterstaat. Bij het PETA plan. Waar we dus ook heel veel energie op willen wekken op het areaal van Rijkswaterstaat. Rijkswaterstaat de heeft heel veel langs de weg. Je hebt straks de Drentse zonneroute A37. Daar zijn wij ook bij betrokken. Als je die een keer googled dan kun je zien dat wij langs die hele weg zonnepanelen neerzetten. Dus uiteindelijk zie je dat gaat ook gebeuren. Maar ook zon op water. We zijn ook betrokken bij op de Slufter waar veel meer deining staat dan op binnenplassen. Daar kun je echt hele grote golven krijgen. Wat er zit in Zeeland of bij het water daar. Met andere woorden.
I: Getijde energie?
G: Gewoon met zonnepanelen maar die ook op beide kanten op kunnen wekken maar die ook tegen hele grote golven kunnen. Er is ook heel veel oppervlaktewater die niet voor recreatie gebruikt wordt waar je ook zon op kunt wekken. Nou als je dan ook bijvoorbeeld op het IJsselmeer heb je wat windmolens staan. Nou stel dat je tussen die windmolens ook wat zonnepanelen neerzet. Dan heb je zon en wind gekoppeld op dezelfde aansluiting.
I: Dan heb je een mooi cluster dat samen kan opereren.
G: Stel nou dat je op de Noordzee zou kunnen.
I: Als er grote windmolens worden neergezet.
G: Dat zijn wel dingen waar je ziet. Ik zie voor zon nog wel heel veel. Voor zon moet je gewoon veel meer opslag hebben maar goed daar wordt aan gewerkt.
I: We hebben het al heel lang over de energiebronnen gehad. U zei dat zout/zoet water ook nog een vorm van duurzame opwekking was. Zijn er verder?
G: Ook opslag.
I: Zijn er volgens u nog meer duurzame manieren om energie op te wekken. Waarvan u denkt dat kan echt gaan bijdragen. Of wordt het toch vooral wind en zon denkt u?
G: Ja goed op een gegeven moment kan het met getijde wel iets. Maar we hebben niet zoveel waterval. Hier en daar hebben we sluizen dus dat kan natuurlijk altijd wel. En misschien ook wel. Of met eb en vloed daar zou je ook iets mee kunnen doen. Maar goed je praat ook dan over vissen en weet ik dat dus iedereen is daar ook niet altijd even blij mee. Maar ik zie wel dat sommige dingen veel meer geintegreerd worden. Zoals ik zeg er zijn nu al panden waar je platen langs de aan een pand neerschroeft. Je verduurzaamt zo`n heel pand dat je dat helemaal met zonnepanelen doet. En dat je op een gegeven moment waar we nu ook over nadenken. Waarom kun je geen zonnepanelen in de vluchtstroken neerleggen. Geintegreerd in asfalt. Ja als je ze dan nog een keer koppelt aan inductieladen in de snelweg. En zo`n snelweg krijgt ook heel veel zon. En als je teveel en ook nog waterstof maakt, want waterstof is natuurlijk ook heel belangrijk he. Voor opslag. Vooral in het noorden zijn ze aan het lobbyen voor waterstof. Of dat je er ammoniak van maakt. Zoals bijvoorbeeld bij de Magnum centrales van plan zijn. Maar die ammoniak of waterstof kun je ook weer gebruiken als je overschotten hebt. Ik zou bijvoorbeeld waterstof voor particulieren in te zetten. Maar wij kunnen niet zoveel waterstof in onze huidige gasleidingen hebben. In de nieuwe zou dat wel kunnen. Maar ik denk dat waterstof en ammoniak veel meer ingezet kan worden voor de industrie.
I: Waterstof, het produceren daarvan ziet u dat als iets wat heel erg op het centrale net zou gebeuren of is dat ook iets wat decentraal heel goed geproduceerd kan worden. Of ga je meer richting TenneT denken met die windmolens op zee.
G: Ik denk dat dat eigenlijk het meest kansrijk is. Dat zal TenneT ook wel gezegd hebben

dat ze van plan zijn zo`n eiland te maken.
I: Ja de North Sea hub. Er ligt al een infrastructuur heb ik meegekregen.
G: Ja eigenlijk liggen daar al buizen van de GasUnie. Nou dan hoef je die kabels niet te leggen. Dan kun je veel meer terugvoeden met gas, met waterstof. Kijk op een gegeven moment dat het best wel komt. Op dit moment is waterstof maken, want sommige zeggen waterstofauto`s maken dat kan, maar als ik zie een paar jaar geleden dan had je nog een 100/150 kilometer met de auto rijden. Ik kan nu al 200 tot 250 kilometer met de auto rijden. Dus met andere woorden. Waterstof om dat te maken zit ook heel veel verliezen in. Dus uiteindelijk kan het wel uit als je het voor niks krijgt. Dus als je elektriciteit voor niks krijgt.
I: Ja als er overproductie is maar je gaat elektriciteit niet gewoon inzetten in de productie in waterstof als dat niet hoeft.
G: Nee als je het direct kwijt kunt in een auto is het veel goedkoper om direct in een auto te stoppen. In plaats van dat je er waterstof van maakt en dat dan in de auto stopt. Dan wordt die auto ook wel elektrisch met een cel. Maar uiteindelijk probeer je natuurlijk zo efficient mogelijk en zo min mogelijk verliezen te maken.
I: Dus u verwacht eerder dat de elektrische auto een grotere rol gaat spelen dan de waterstof auto. Gewoon puur omdat je elektriciteit om moet zetten in waterstof.
G: Ja op dit moment zie ik dat wel. Er zijn ook collega`s die het anders zien maar ik zie het dat op een gegeven moment waterstof autos wel heel erg duur zijn. En dan is ook nog de vraag wat gaat waterstof doen? En ik denk gewoon dat waterstof op dit moment veel meer voor industrie ingezet gaat worden. En bijvoorbeeld wel voor bussen of treinen of vrachtwagens. Maar goed Tesla en anderen gaan ook vrachtwagens elektrisch maken en ook bussen elektrisch. Ja waarom doen ze dat niet waterstof?
I: En als je dan inductie laden krijgt dan hoef je eigenlijk niet eens meer.
G: Dat hoeft niet maar kijk in een paar jaar zie je al dat die accu is verbeterd. Tuurlijk ik weet ook wel van mijn collega`s. Die zeggen als ik hard rij en in de winter ja kan ik er iets minder lang mee. Maar uiteindelijk het is net zoals ik vandaag met de trein ben gekomen. Je moet er gewoon op inzetten. Kijk ik moet 170 kilometer rijden vanuit Arnhem om hier naartoe te komen en als ik hier zou zijn dan had ik mijn auto bijvoorbeeld neergezet bij het winschoterdiep. Daar hebben we allemaal opladers. Dan had ik hem ingeprikt had ik de fiets gepakt en was ik hierheen gefietst. Uiteindelijk moet je daar wel rekening mee houden. Stel nu dat je een keer een half uur of drie kwartier moet laden omdat ik gewoon net niet ergens kan komen. Het kan soms ook zijn dat ik maar 10 of 20 minuten hoef te laden. Afhankelijk van waar ik moet zijn. Opzich merk ik ook van collega`s die ook elektrische autos hebben die zeggen tuurlijk soms moet je even laden maar dan klap je je laptop open of je pakt je smartphone dan ga je al je mailtjes bij langs. En stuur je wat weg. Je mag toch niet met je smartphone achter je auto zitten.
I: Het is wel een goede reden omdat dan te laten want het is voor sommige mensen nog wel moeilijk
G: Ja dus dat kun je op een gegeven ook wel oplossen. Uiteindelijk moet je je er wel op instellen. Maar ik zie thuis als ik thuis kom heb ik ook een laadpaal staan en dan plug je hem gewoon in.
I: Ik kwam toen bij TenneT op waterstof omdat ik vroeg naar methodes om op te slaan. Wat ziet u als de meest kansrijke of voor de hand liggende de beste methode om overtallige elektriciteit op te slaan.
G: Ik denk dat dat decentraal toch wordt dat wat laag in het net opgewekt wordt. Om de balans zo veel mogelijk zo laag mogelijk te houden. Dus je hebt op een gegeven moment decentrale opwekking op het laagspanningsnet. Ik lever aan jou, jij levert aan mij en als we allebei leveren dan leveren aan kleine middenbedrijven. Als dat is dan proberen wij wat te

regelen in ons huis om dat aan te passen. En als er bijvoorbeeld een winkelier is met een albert heijn dat die z`n koeling even wat harder zet. Zodat die op een gegeven moment niet om 6 uur gaat koelen maar mijn elektriciteit van mijn zonnepanelen in zijn koelapparaat stopt. Als dat gebeurt dan komt dat in ieder geval niet bij TenneT. Op het grotere vlak op het middenspanningsnet MSD en AMNS. Grotere parken zitten daar aangesloten. Die kunnen in principe ook naar beneden dus dat kan ook opgenomen worden door het distributienet. En alles wat niet door het distributienet komt dat komt bij TenneT. Maar op die grote HSM station daar zitten ook industrieen. Die industrieen moet je hetzelfde mee doen als de huishoudens. Proberen zoveel mogelijk te doen. En dan kun je kijken als ik dan te weinig heb en ik kan dat niet opslaan. Dan kun je kijken, Wat is dan efficienter qua kostprijs, hangt gewoon van de kostprijs af. Doen we waterstof van maken, gaan we sommige dingen in Magnum centrales, grote eenheden bijvoorbeeld ammoniak van maken. Of gaan we perslucht wat ze dus eigenlijk in Drenthe iets willen doen. Of met zoet en zout water accu`s. En bijvoorbeeld koppeling met het buitenland. Kan het bijvoorbeeld naar Noorwegen. Waar we water.
I: Zoals ik het begrijp zegt u. Voordat we het opslaan gaan we eerst kijken of we het slimmer kunnen verdelen.
G: Ja dat zou het ideaalst zijn. Het is nog allemaal moeilijk nu maar ik denk dat dat het ideaalste is. Kijk TenneT kijkt alleen naar het grote systeem die kijkt alleen maar naar alleen die grote centrales. Maar uiteindelijk zie ik ook dat er heel veel in onze lagere netten gedaan wordt. Omdat al daar zo goed mogelijk te kunnen verdelen hoeven wij onze netten ook niet aan te passen. Dus dat zal het ideaalste zijn. En dat kan ook met accu`s he. Met elektrische auto`s. Maar kan ook met bussen.
I: Ziet u daar een betrouwbaar opslagsysteem in. In de elektrische auto.
G: Ja als je volume maar groot genoeg is Ik bedoel ik weet jaren geleden in de EGD tijd toen ik pas net begon, hebben wij bijvoorbeeld, toen mochten wij alles nog. Toen mochten we elektriciteit verkopen en opwekken. We mochten alles. En toen konden wij op een afstand met één druk op de knop dan hoef je niks moeilijks te doen, konden wij alle WKK`s 110% laten draaien en we konden alle assimulatieverlichting afgooien. Hoe simpel wil je het hebben? We konden toen heel goed uit de piek komen. Toen hadden we nog een paar keer een piek dat we heel veel voor die piek moesten betalen. Toen we zo uit de piek konden komen was dat heel mooi. Dus we gooien al die WKK`s op 110%. En dat kan nu ook. In principe zouden ook alle leveranciers die auto`s contracteren. Bijvoorbeeld dus ik noem maar wat. Shell heeft dat overgenomen. Al die laadpalen. Waar wij straks dus ook laadpalen van hebben.
I: Green Motion?
G: Ja. Dus als zij zo`n contract maken en zeggen jongens ik heb zoveel van die auto`s. Dan kan dat.
I: Als ik uiteindelijk zou vragen die kan als opslagmethode dienen aan de ene gaat het ook maar vragen van het elektriciteitsnet aan de andere kant.
G: We hebben nu toch al Smart laden
I: Hoe moet ik dat zien?
G: Dat die gewoon kijkt hoeveel auto`s zitten er achter het net?
I: Al die paaltjes worden bijgehouden wat aangekoppeld is?
G: Ja dat doen we ook al op ons bedrijf. Dat heel veel mensen laden tegelijk dan vliegt alles eruit. Nou ales alles gelijktijdig laadt dan vliegt alles eruit. Maar wat we nu dus doen. Iedereen stelt in dan wil ik weer weg. En ik wil dan daar heen dus ik wil zoveel kilometer kunnen rijden. En als je dat instelt dan laadt die automatisch afhankelijk van wanneer je weggaat. En dan word ik wel geladen maar jij niet. Want jij gaat pas om 4 uur weg.

I: Een slim laadsysteem dat is wel belangrijk

G: Ja dat werkt gewoon

I: Stel het is nu op hele kleine schaal en het gebeurt veel bij de netbeheerders. Stel nou heel Nederland gaat elektrisch rijden. Hoe gaan wij dat netwerk van laden organiseren? Krijgt iedereen een laadpaal voor zijn huis. Of hoe moet ik dat zien?

G: Kijk in de stad Groningen zijn ze daar wel over aan het nadenken. Maar die hebben sowieso altijd al iets met parkeren en auto`s. Autoluw maken van het centrum. Die denken wel na met een auto en parkeerbeleid. Moeten wij bijvoorbeeld niet veel minder auto`s in de wijken laten. Maar ook zelfs in het centrum. Dus ik denk straks veel meer aan deel auto`s. Elektrische deelauto`s die je ook afroept je zegt van dan wil ik een auto hebben dan komt die zelf voorrijden.

I: De zelfrijdende elektrische deelauto. Daar ziet u een belangrijk

G: Ja allereerst heb je dan minder auto`s dus je gaat efficienter om met je middelen.

I: De auto`s gaan dan zelf regelen met opladen.

G: Ja dat kan. Er zijn al wel mogelijkheden dat auto`s straks op een inductie laadplaats gezet en die wordt dan opgeladen.

I: Heeft u daar veel vertrouwen in?

G: Jawel ik heb veel vertrouwen in techniek. Kijk sommige dingen.... (1:24:56)

I: Ik vind het wel mooi dat dit concept met de zelfrijdende auto dat is ook precies wat ik bij TenneT heb gehoord. Hun zeggen dat is (1:25:35).

G: CO2 is veel te goedkoop. Alle bedrijven hadden gewoon CO2 rechten. CO2 kost niks. Wat ze met de banken gedaan hebben met slechte dingen opkopen Centrale Bank of Europa. Dat hadden ze eigenlijk voor die CO2 rechten moeten doen. Die waren zo goedkoop Voor 50 of 60 miljard of 100 miljard hadden ze al die CO2 rechten moeten opkopen. Die kosten bijna niks. Het voordeel is dat de CO2 prijs gigantisch omhoog gaat. En die kolencentrales kunnen helemaal niet concureren met anderen. Met andere woorden dan zijn de kolencentrales veel duurder dan de gascentrales. Hoef je helemaal geen subsidies meer voor duurzame energie. Je hoeft geen enkele subsidie meer. Wij subsidieren wij niet duurzame energie. Wij subsidieren die grijze massa. Dat is toch helemaal zot. Ja iedereen zegt die zon en windparken draaien op subsidie. Nee die kolenbakken draaien op subsidie.

I: Omdat CO2 niet belast wordt

G: Zij maken veel CO2. Dat moet gecompenseerd worden door duurzame energie. Dat is toch te gek voor woorden? Als ze 80/90. Heb je het Quintel model wel eens gezien? 1:29:16 (...) 1:31:18

I: Dus je ziet nu dat de overheid inzet op de CO2 opslag. Dat is eigenlijk gericht op het centrale gedeelte van de kolen en gascentrales omdat af te vangen en op te slaan. Waardoor eigenlijk het verbranden van grijze energie rendabel blijft. Denkt u ook dat zoiets op decentraal niveau kan gebeuren?

G: Nee kijk allereerst is het al een behoorlijk experiment. Er zijn er heel weinig die dit doen. Uiteindelijk zie ik er veel meer in wat sommige ook zeggen. Ga alsjeblieft investeren in dingen die. Net zoals bijstook van biomassa in kolencentrales. Er is meer dan een miljard naartoe gegaan. Dat is toch doodzonde? Met een miljard hadden wij ik weet niet hoeveel zonnepanelen kunnen doen. Of aan isolatie. Ik noem maar wat.

I: Het is eigenlijk de vraag of het verstoken van biomassa wel duurzaam is.

G: Ja het komt met grote schepen hierheen maar waar het wordt weggehaald en hoe duurzaam is dat dan? Ik snap wel dat ze dat willen doen maar. Kijk ik zou gewoon CO2 proberen om te zetten wat al kan. In bijvoorbeeld stenen of bouwmaterialen. Hoe kun je op een gegeven moment CO2 gebruiken.

I: Kassen bijvoorbeeld.
G: Ja dat gebeurt al wel maar uiteindelijk moet je gewoon kijken hoe je CO2. Dan vang je het wel af maar dan maak je er een product van. En ik zou gewoon zeggen die CO2 moet je gewoon niet meer uitstoten. Want als het veel goedkoper wordt om het op te slaan, er gaat heel veel subsidie heen. Dan betekent dat die subsidie niet naar hernieuwbare energie gaat.
I: Kan maar één keer worden uitgegeven.
G: Dan zegt de industrie nou heb ik voldoende gedaan. Dan blijven ze gewoon door produceren in plaats van dat ze nu gaan ze creatief kijken hoe ze wel CO2 kunnen verminderen.
I: Hoe u dit schets is dat ook zo dat je vaak hoort dat het beleid van de overheid in Nederland dat daar nog niet echt een richting in zit?
G: Wij zijn natuurlijk een compromisland en je merkt gewoon de ChristenUnie wil veel meer verduurzamen en D66 ook wel. Maar de VVD die wil gewoon het bedrijfsleven niet aantasten. Die zijn heel bang dat het bedrijfsleven onderuit gaat.
I: Als het economisch rendabel is dan doen we het en als het niet rendabel is dan blijven we er met de handen van af.
G: Sowieso als het op een gegeven moment als het het bedrijfsleven op achterstand zet dan willen ze dat niet. In plaats van dat je nu ziet dat een Google en dergelijke die komen naar de Eemshaven omdat er veel hernieuwbare energie zit. Er zijn heel veel bedrijven die zeggen nou als er een stok achter de deur zit dat wij moeten verduurzamen dan helpt dat ons ook. Maar het moet wel consequent beleid zijn. Dus ik ben wel heel erg voor dat er een energiewet komt 1:35:07 (...)1:35:41
G: We hebben nu 2 keer 6 miljard vorig jaar is er heel veel ingedient maar er werd ook heel veel naar de bijstook en straks weer bang dat misschien ook de CO2 uit dit potje gehaald wordt. Dan denk ik als dat gebeurt dat betekent dat wij weer op achterstand komen. Niet wind en zonne parken gaan realiseren. Ik ben ook een voorstander van lokale intiatieven. Echt van onderop lokaal dat ook.
I: Individuen bij betrokken.
G: Ja maar ook dat het geld dat geïnvesteerd wordt. Ik ken projecten van lokale initiatieven waar ze 2,5 miljoen bij elkaar halen om op een gegeven moment een groot zonnepark te realiseren. En dat kost wel meer dan 6 miljoen maar waar de mensen 2,5miljoen bijdragen en de mensen krijgen de residuen. Ze verdienen er mee en daar kan iedereen aan meedoen. Ik denk dat dat ook door gemeentes gestimuleerd moet worden voor iedereen. Hoe je dat precies moet doen dat weet ik niet maar je zou in principe
I: Dat is misschien ook gemeentespecifiek.
G: Maar ik zie dus dat het heel belangrijk is. Dan krijg je draagvlak. Mensen zien dat hernieuwbare energie ook leuk kan zijn. Het hoeft niet altijd vervelend te zijn. Mensen leren dan ook die zonnepanelen hebben. Dan zie je al heel snel dat mensen ook wat meer nadenken over duurzame energie. Kijk zoveel wek ik dan op en zoveel verbruik ik. Ik kijk ook altijd. Ik wil quite uitkomen. Ik heb maar 9 paneeltjes maar ik kan met die 9 paneeltjes bijna helemaal redden. Ze staan allemaal op het zuiden want ik heb een plat dak en we zijn met zn tweeën. Maar ik heb wel heel veel dingen gedaan, LED verlichting om mijn energie naar beneden te krijgen. Een afwasmachine hebben wij wel dat vinden wij makkelijk maar die kan net zo goed vol draaien in plaats van half vol. 1:38:45 (...) 1:40:45
G: Uiteindelijk zijn het de simpelste dingen die goed werken. En ook met de slimme meter dat je alles kunt zien. Dus je kunt precies hoeveel je vorig jaar hebt gedaan en hoeveel je nu hebt gedaan. Ik wil gewoon niet meer dan vorig jaar hebben. Ik wil het liefste eronder komen. Heb je nog meer vragen?

I: Ik heb de kern gehad. Ik heb de verschillende vragen gehad. Over de opwekmethodes, de balanceermethodes over de vraag en aanbodkant dat je balanceert. Met het opslaan van energie en de vraagkant met de slimme meters bijvoorbeeld.
G: Ja maar ook systemen in het huis die daarmee kunnen helpen. En met flexibele tarieven. En als mensen weten en je koppelt dat. Tarief is nu goedkoop en zet nu mn afwasmachine en wasmachine gereed en zet ik aan als die een seintje krijgt.
I: Slimme huishoudelijke apparaten die communiceren met de slimme meter.
G: En dan eventueel opslag als het goedkoop wordt. Of een buffervat met warm water of dat je iets met zoet zoutwater accus wat doet.
I: Zijn zoet zoutwater accus voor huishoudelijk niveau of kan dat ook groter?
G: Dat kan maar dat kan ook groter.
I: Dat zou ook als bijvoorbeeld buurtbatterij kunnen dienen.
G: Ja
I: Wat u heeft gezegd dat er wel veel in het decentrale net geinvesteerd moet worden. Het regionale en lokale net. Daar heb ik antwoord op. Ik heb CO2 gevraagd.
G: Decentraal is dat te duur. Dat heeft decentraal te weinig zin. De methode is te duur en de veiligheid die je daarbij moet hebben. Maar ik denk dat dat voor een TenneT/ GasUnie als het uberhaubt of een bedrijf die dat dan overneemt. Dat je dat rechtstreeks in oude gasinfrastructuur legt en dat je dat daar opslaat. Ik verwacht ook niet dat we dat in Nederland in de grond in zoutcavernes opslaan. Wat wel eerst het idee was.
I: Hier in Groningen wil ze wel CO2 in de grond stoppen?
G: Volgens mij niet hoor. Volgens mij zijn ze hier niet. Als het ergens wordt dan wordt het op zee. Maar wat ze wel in de grond willen hebben is eventueel waterstof. CO2 wilden ze jaren geleden hier al waar ze RWE centrale hebben gebouwd. Ik was er wel bij betrokken. Toen wilden ze in de buurt van Zuidhorn of iets dergelijks. Daar hadden ze een lege caverne. Daar hadden ze het idee om CO2 op te slaan. Maar uiteindelijk is dat toen afgewezen en is dat door CDA minister. Daar waren ze hier niet zo dol op.
I: Ik had nog wat afsluitende vragen. Je hebt nu al een wijk wat redelijk autonoom oppereert. Dan heb je het over Lombok. Denkt u dat zoiets op grote schaal te kopieren is of is dat heel erg afhankelijk van het type huizen dat je hebt.
G: Lombok zoals ik het begrijp. Daar wonen heel veel mensen die ook wel wat te besteden hebben.
I: Dat is een duurdere wijk?
G: Ja dat dacht ik deden ze daar ook niet veel met Tesla`s? Met opslag? Of was dat iets anders?
I: Ik heb er het één en ander over gelezen.
G: Kijk dat zeggen sommige wel meer. Op een gegeven moment hebben wij geen netwerkbedrijven meer omdat iedereen zijn huis autonoom gaat maken. En dan kun je helemaal afgesloten worden van elektriciteit en gas. Nou dat kan en als ze dat willen is dat prima. Alleen ik merk wel dat je dan wel heel veel opslag met realiseren. Kijk want dag nacht wil nog wel. Maar kun jij ook zomer/ winter overbruggen. Kun je in de zomer zoveel opwekken en kun je dat opslaan in je huis dat je de winter daarmee ook kunt.
I: Plus je hebt opslagverlies als je het langer moet opslaan.
G: En dat er dan ook nog. Het mag hobby zijn. Het mag ook heel veel geld kosten maar als je dat wilt doen kost dat heel veel. Je kunt veel goedkoper het net ingeschakelen.
I: Je zegt het ook al. Als je het zelf wilt doen kost het veel geld en dan is het voor 90% van de bevolking niet haalbaar.
G: Nee ik denk dat de meeste mensen dat ook niet doen. Daar kan ik veel beter leuke dingen voor doen in plaats van dat ik heel veel probeer op te slaan.

I: Dan ga je liever samen werken met buren of de buurt.
G: Ja hoe groter dat je die cirkel hoe meer je daar op een gegeven moment voordeel bij hebt en sommigen zeggen ook wel we willen het hele dorp energieneutraal, dat het helemaal op zichzelf staat en dan helemaal geen koppeling met het normale net. Maar ik vraag me af. Ook een stad ofzo. Ik zie niet zoveel in de lokale energienetten want ik denk de prijs wordt europees bepaald. Doordat jij zegt nou uiteindelijk zet ik een hek om Groningen en Groningen is energieneutraal en wij willen geen koppeling meer met de rest van het net. Dan moet je heel veel opslag hebben. Je moet hele zware netten hebben voor bepaalde momenten. Uiteindelijk is de vraag is het wel te betalen en ten tweede vind je het dan nog wenselijk? Want je moet het wel overslaan die kosten naar al je aangeslotenen. Het is niet voor niks dat wij een netwerkbedrijf zijn en alles socialiseren. Dus uiteindelijk elke aansluiting kost evenveel. Met andere woorden dat is het voorbeeld ervan dat het systeem in Nederland en netwerkbedrijven hebben die gecontroleerd worden door ACM.
I: Decentrale orientatie dat betekent niet dat je alleen op dat gebied focust. Misschien daar vind de opwekking plaats maar er moet echt wel een intensieve samenwerking zijn met het liefst heel Europa.
G: Ja ik denk dat dat het meest stabiele en goedkope net is.
I: Wat denkt u dat echte gamechangers zijn? Heeft u iets specifieks in gedachte?
G: Ik denk dat de grote verandering wel is CO2 prijs. Ik denk als dat echt gaat veranderen dat dat heel veel uit gaat maken. Ik denk ook wel. Ik ben ook een voorstander van warmtenetten. Warmtenetten vind ik gewoon. Dan moet het warmtenet dat concurreert met een goedkoop gasnet. Wij leggen gasnetten aan ik wil niet zeggen voor niks. Maar die kosten ten opzichte van een warmtenet bijna niks. Bijvoorbeeld wat ze hier doen met geothermie. Sommige gebieden kan geothermie maar misschien ook hier wel.
I: Ze hebben dat hier bij het universiteitscomplex?
G: Nee dat is dus afgewezen. Dat is juist het grote probleem. Geothermie was te gevaarlijk hebben ze gezegd. Daar stond de hele pers vol van afgelopen dagen. Daar is bijna een wethouder op gevallen. Uiteindelijk gaan ze wel voor alternatieven kijken. Maar uiteindelijk denk ik dat je een mix moet hebben. Ik ben er heilig van overtuigd van het type woning en de mensen die er wonen. Wat hebben ze te besteden en wat is er in de buurt? Is er in de buurt een warmtenet of restwarmte wat de lucht in gaat. Kun je dat gebruiken en dat moet dan ook duurzaam zijn. Het moet niet uit een kolencentrale komen want het moet wel uit iets komen dat een restwarmte is wat ingezet kan worden.
I: Industrie?
G: Ja maar ook het riool. Ik ben ook voor hernieuwbare gassen. Zijn we samen met de GasUnie mee bezig. Dat kan een stuk biomassa zijn inclusief wat wij mengen van waterstof en wat ik weet. Dat wordt een nieuw gas en daar gebruiken we onze huidige netten voor. En dan kunnen wij met warmtepompen, die gebruiken alleen nog maar warmte voor tapwater. Wat anders een grote elektriciteitsvraag is en als het een keer -2/ -3/ -4 / -5 graden wordt. Dan gaat die gaskachel aan. Maar dat is dan geen aardgas.
I: Dus eigenlijk wat u zegt dat we slimmer met onze warmtebronnen omgaan. Kijken waar er warmte verloren gaat
G: Ja. Ik hoop dat de overheid gaat tenminste dat moet nog door de kamer dat er geen aansluitplicht is voor nieuw voor gas. Dat er een warmtewet komt waar iedereen recht heeft op warmte en dat de lokale overheden samen met de netwerkbedrijven mogen uitzoeken van waar gaan we die warmte die nu nog uit aardgas komt hoe gaan we dat op een gegeven moment vervangen door duurzaam. Dat kan dus een warmtenet zijn of een hybride systeem kan all elekctric zijn en er is ook een transitiemodel. Je kan best zeggen we gaan nu naar een hybride systeem. 70% van het gas hebben we dan al verminderd en

het kan best zo zijn dat er na 10/15 of 20 jaar naar all electric gaat. Dat er dan alsnog de gasleidingen eruit getrokken worden. Omdat die gasleiding dan vervangen moet worden. en we dan een moment hebben om weer te veranderen. Maar uiteindelijk hoeven we er maar weinig aan te veranderen want je hebt al een.. Een warmtepomp moet toch soms vervangen worden en dan moet je een groot buffervat hebben je moet misschien iets anders hebben. En warmte koude opslag er zijn heel veel mixen waaruit je kunt kiezen. Het zal niet één meer worden zoals we vroeger hadden. Elektriciteit en gas.
I: Je moet gebiedsspecifiek kijken wat er is. Waar verliezen we energie? Als we daar ons op focussen dat scheelt echt heel veel. Daarmee helpen we de transitie echt
G: Ja daarmee zijn we nu bezig met gemeentes om in de omgevingsplannen energie te maken. En dat willen wij dan hebben dat dat verankerd wordt in de omgevingswet als die een keer komt. Want daar zit energie helemaal niet in. Als je je verdiept in de omgevingswet. Energie is daarin helemaal geen issue. En dat is heel gek.
I: Ik ben er niet heel bekend mee.
G: Nouja je bent met ruimtelijke ordening en ruimtelijke plannen bezig. Nou die energiewet moet je maar eens kijken die omgevingswet wat elke keer weer uitgesteld wordt maar waar we nu wel van door krijgen hoe we langzamerhand. Dus wij zijn nu een beetje aan het pionieren hoe kunnen wij bijvoorbeeld energieomgevingsplannen maken die nog niet moeten maar de gemeentes zouden wel een warmteplannen moeten maken. En wij vinden eigenlijk maar ik denk dat EZ daarin wel mee gaat. Dat we geen warmteplan meer maken maar dat we een energie omgevingsplan maken waarin ook warmte deel van uit maakt. Want je moet zowel elektriciteit als warmte.
I: Je moet het hele energiesysteem meenemen.
G: Ja. Dat is wel handiger om dat te maken. Daar zijn we nu heel erg druk mee bezig om dat op te pakken.
I: Allerlaatste vraag die ik heb. Heb ik nog iets gemist?
G: Nee ik denk dat we redelijk compleet zijn geweest
1:55:35 (...)
I: Heel erg bedankt voor uw tijd.

Apendix 6: Desk research sources

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