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Geographical Information Management and Applications

Assessment of open electricity network data by renewable energy scenarios

Projection of renewable energy concepts on existing electricity networks.

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FOREWORD

De masterthesis. Het kroonstuk op een masteropleiding. Bijna een heel jaar heb ik me gestort op een Open Asset dataset van Enexis. Het daarvan uitpluizen was een grote uitdaging en het analyseren leidde tot veel trial-and-error onderzoek. Een netwerk waarvan van te voren nog niet duidelijk was hoe het in elkaar zou steken en op welke manier het bruikbaar is. Door middel van een scenario passend bij een actueel energievraagstuk heb ik gekeken in hoeverre de Open Asset data geschikt is voor een dergelijke transitie.

En nu is het af. Een scriptie die mede tot stand is gekomen door mijn steun en toeverlaat; Elisa, Pulles en Simon. De vrienden van het van Unnik. Mijn koffiemaatjes tot in den treurnis. En boven alles drie mensen die een jaar lang mijn gemekker en gezeur hebben mogen aanhoren over lay-out, de koffiepas, tijd-efficiënte routes en speltactieken bij DotA. Zonder hen was het schrijven van mijn thesis een stuk minder spectaculair geweest.

Tot slot wil ik mijn supervisor Ron van Lammeren bedanken voor zijn enthousiasme en goede tips. Mede dankzij hem heb ik deze thesis tot een mooi eindproduct weten af te ronden. Hij koppelde mij aan de juiste mensen om lastige doelen op te lossen, of stuurde interessante documenten en artikelen die goed aansloten op mijn thesisonderwerp.

De grootste les die ik uit deze masterscriptie heb geleerd is dat je onderzoek heel nauw moet afbakenen, zeker als je aan een onderwerp werkt waarover je nog niet veel kennis hebt. Ik heb geen technische achtergrond en het hele elektriciteits-domein was daardoor voor mij aardig onbekend. In het uitzoeken daarvan kostte niet alleen veel tijd, maar leidde ook tot het voortdurend verder afbakenen van het onderzoeksdoel.

ABSTRACT

Keywords: energy transition, energy grid, smart grid, renewable energy, open data

In the 21th century transparency and openness from the commercial sector towards their customers has become an important aspect of marketing. This also accounts for the net operator Enexis, who has made their network and consumption data openly available on the internet. Simultaneously an energy transition is taking place in the developed world in which fossil fuels are getting replaced by renewable ones. Local renewable energy initiatives will reply to open data when available. This led to the question whether it is possible to use this Open Asset data of Enexis to explore an energy transition scenario.

In this research an energy transition scenario has been constructed comprising of 50% electricity production from solar energy and 50% electricity production from wind energy. The suitable areas for these two types of renewable energy have been identified with a multi-criteria analysis using both the Open Asset dataset from Enexis and various other datasets. In addition to that, service areas were generated from the substations transformers to identify which service points are connected to which technical buildings.

The Open Asset dataset provided by Enexis contains a lot of information in point, polygon and polyline shape files. However performing an entire energy transition on the data is not possible due to various reasons. First, the metadata provided in the Open Asset dataset contains not enough metadata in order to effectively calculate the capacity within the service areas. Second, there is a high amount of uncertainty in the interconnectivity of the grid lines; this is caused by the lack of metadata and the lack of topology rules. Third, the network in the case area has a higher complexity than expected based on literature.

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LIST OF ABBREVIATIONS

	Dutch	English
AC		*Altering Current*
AHN	*Actueel Hoogtebestand Nederland*	*Height map of the Netherlands*
BAG	*Basisregistratie Adressen en Gebouwen*	*Registration of addresses and buildings*
BGT	*Basisregistratie Grootschalige Topografie*	*Registration of large-scale topography*
DC		*Direct Current*
EV		*Electric Vehicle*
ESS		*Energy Storage Solutions*
GW		*Giga-watt*
GWh		*Giga-watt-hour*
HVDC		*High-voltage Direct Current*
kV		*Kilo-volt*
kW		*Kilo-watt*
kWh		*Kilo-watt-hour*
MCDM		*Multi-criteria Decision Making*
MW		*Mega-watt*
MWh		*Mega-watt-hour*
NB		*Nota Bene*
PV		*Photo-voltaic cells*
RE		*Renewable Energy*
RQ		*Research Question*
V		*Voltage*

1

INTRODUCTION

1. Introduction

In this chapter the problem description and the research outline are presented. The chapter starts with the motivation, and social and academic relevance of the topic. Secondly a brief introduction about the Open Asset dataset that has been assed is presented. After that the research objectives and corresponding research questions are shown followed by the assumptions and constraints that have been made in this research. The chapter finishes with a brief overview of the thesis structure.

1.1 Problem description

The 21th century is marked by its excessive push to become sustainable and green in the western world. Treaties and strategies such as the Kyoto Protocol (United Nations, 2014), The Lisbon Strategy (European Commission, 2000) and its follow-up; Europe 2020 (European Commission, 2010) have forced countries such as the Netherlands to invest extensively in sustainability and renewable energy sources. This active approach in changing the current way of electricity production and consumption is often referred to as the energy transition (see section 4.1 – *Energy Transitions*). But alongside this trend of becoming sustainable and 'green' also other notable trends are occurring within the Netherlands. Many of these trends can be found in chapter 3 – *Contextual framework*. Among these trends are the growing share of renewable energy, the increasing amount of decentral produced electricity with solar panels and the upcoming electrical vehicle that will increase the electricity consumption.

One of the previously mentioned trends shows that the Netherlands is facing an energy transition in which solar energy will take an increasing role. However these solar panels have caused regional issues in Groningen, The Netherlands, as well. According to the Dutch Broadcast Foundation (In Dutch: Nederlandse Omroep Stichting (NOS)), there are already too much solar panels in Groningen. Problems arise on very sunny days when the network is not capable of handling all the extra electricity that is put into the network (NOS, 2015). This led in total to 38 complaints of solar panel failures in the province in July 2016 (Van Sluis, 2016). In Zonderschot, Belgium, an extra electricity transformer had to be installed in a neighborhood to accommodate the solar panels in the area (Provoost, 2016). In addition to that the placement of solar panels is a process which is mostly initiated by local population and happens on a very local scale. Often the network operator is not notified of changes made in the electricity production in the region. On a small scale this is not disturbing, but as the examples above pointed out, issues might occur when the network is not modified in time. A geographical challenge is there for network operators and municipalities to deal with this energy transition and optimize the electricity network.

The Netherlands and Belgium are not the only countries facing this challenge. In the last few years many researches have been done on exploring the possibilities for a 100 percent renewable energy production in different countries and regions. Among these are for example Australia (2010), Denmark (2007), Finland (2016), Germany (2016), Ireland (2011), Israel (2017), Japan (2003), New Zealand (2010), Nigeria (2017) and Portugal (2011). All these researches take one or more different scenarios into account of which at least one can be identified as a '100% renewable energy'-scenario. Some of these researches are used to identify key-factors for modelling an energy transition scenario is a smaller case area.

This research focusses on assessing the Open Asset data because community initiatives may reply in the first place these open data sets to study and design their renewable project. It tries to identify the strength and weaknesses of the Open Asset dataset. In addition to that this research will set out requirements for an actual transition and tests the Open Asset data network to see to what extent the dataset is suitable for energy transition modelling.

N.B. Dear reader, strictly seen is energy production or consumption impossible. According to the law of energy conservation, energy cannot be created nor destroyed. However, in academic literature and modern writing energy production and consumption are often mentioned instead of energy conversion. Therefore, in this thesis 'energy production' and 'energy consumption' are used when energy conversion is taking place.

1.2 Open Asset data of Enexis

This research focusses on assessing the Open Asset dataset of Enexis. It is provided by the network operator Enexis and is openly accessible online. As a network operator, Enexis is responsible of ensuring a reliable and stable electricity network in a large part of the Netherlands. However, households in the Netherlands can select individually which electricity provider they want.

The Open Asset dataset of Enexis consists of various point, polyline and polygon shape files, in addition to that two Excel documents with metadata are attached (Enexis Open Asset Data, 2016). All together the Open Asset dataset consists of 16 different layers and two separate documents. All files, their type and size are shown below in table 1.1. A more detailed overview of the individual dataset parts can be found in appendix I.

Table 1.1 Detailed overview of the Open Asset data of Enexis

#	Type	Contains	Size	Attributes
1	Point	Electrical vehicle charging point	142 kB	665 (points)
2	Point	Multi-storey connection point	18,080 kB	79,646 (points)
3	Point	Service connection point	567,649 kB	2,522,883 (points)
4	Point	Street furniture	11,164 kB	44,298 (points)
5	Point	Street light connection	312,754 kB	1,376,118 (points)
6	Polyline	Low voltage connection cable	1,777,196 kB	
7	Polyline	Low voltage distribution cable	1,143,916 kB	
8	Polyline	Middle voltage distribution cable	348,881 kB	
9	Point	Connection box (point)	10,078 kB	62,652 (points)
10	Polygon	Connection box (polygon)	16,924 kB	62,652 (polygons)
11	Point	Distribution box (point)	10,406 kB	66,275 (points)
12	Polygon	Distribution box (polygon)	19,080 kB	66,275 (polygons)
13	Point	Technical building (point) (low voltage)	8,320 kB	51,354 (points)
14	Polygon	Technical building (polygon) (low voltage)	15,213 kB	51,354 (polygons)
15	Point	Technical building (point) (middle voltage)	8,425 kB	51,369 (points)
16	Polygon	Technical building (polygon) (middle voltage)	15,429 kB	51,369 (polygons)
17	Excel	Metadata attributes	40 kB	
18	Excel	Metadata objects	14 kB	

The Enexis Open Asset dataset covers most of five provinces in the Netherlands. These are Groningen, Drenthe, Overijssel, Brabant and Limburg. Besides that they take care of small parts of Flevoland and Gelderland as well. For the assessment however, a smaller case area has been selected and used. The process of selecting this case can be found in chapter 5 – *Case study*. The data is line with the INSPIRE regulations set by the EU, according to Enexis, they were the first European net operator to make their data in line with these regulations (Enexis, 2016)

Enexis provides a disclaimer with the Open Asset dataset as well. In this they state that they can't guarantee the correctness of the data, the actuality and the consistency. In addition to that Enexis remains the only (intellectual) owner of the dataset, furthermore they state that they are not responsible for any issues that might occur when using the data. The disclaimer Open Asset data has been added to this report and can be found in appendix II.

In this research the polyline layers are put together into a network and assessed. In order to make this more successful only a small part of the network has been assessed. In addition to that the individual connection and distribution boxes and technical buildings have been attached to this network to identify service areas.

1.3 Research objectives

The main research goal of this thesis is to assess the open energy network data in regard to possible energy transition scenarios. In order to achieve this goal a set of objectives with individual research questions have been listed to support the main research question. The objectives will follow-up each other making use of the knowledge gathered in the previous objective. The four objectives of this research are in table 1.2, the research questions per objective can be found in section 1.4 – *Research questions.*

Table 1.2 The four objectives of the research

Objective 1:	Construct both a contextual and a theoretical framework regarding electricity production, consumption and transitions.
Objective 2:	Select a case area for the data quality assessment
Objective 3:	Analyze and explore the quality of the open energy dataset, and the current state of the case area in general
Objective 4:	Assessing the Open Asset dataset regarding the set requirements for an energy transition scenario

1.4 Research questions

In order to achieve the objectives mentioned in the previous section, research questions are formulated to support each objective. Furthermore this section explains the exact aim and approach of every objective. In addition to that the link between the objective and the overarching objective is shortly explained.

1.4.1 Objective 1
Construct both a contextual and a theoretical framework regarding electricity production, consumption and transitions.

The first objective of this research has a very theoretical approach. The objective is to gain broad understanding of the topic and all related factors. It makes use of academic papers and secondary data, mostly statistics of Statistics Netherlands. Research question regarding this objective are:

Q1 – What is the current state of electricity production and consumption in the Netherlands?
Q2 – How are electricity networks conceptualized in literature?
Q3 – What are characteristics of spatial energy transitions?
Q4 – How are energy transition scenarios designed for different regions?

This objective is necessary to identify what data is needed. This objective contributes to the main objective in the sense that it describes electricity production, consumption and network in an academic way. The questions related to this objective are answered in chapter 3 – *Contextual framework* and chapter 4 – *Theoretical framework*.

1.4.2 Objective 2
Select a case area for the data quality assessment.

The second objective is necessary to select a smaller part of the network to assess. The whole network dataset is too big and complex to assess in one thesis. Selecting this area requires a list of conditions that the area should met in order to be suitable for the rest of the research. The following research questions are to support this objective

Q1 – Which requirements does the case area have to meet?
Q2 – Which method is needed for selecting a case area?
Q3 – Which area is suitable and will be selected for further research?

The first research question links directly to the information found by the first objective. It looks at the conceptual model of the electricity grid and the current state of the electricity production and consumption in the Netherlands. It uses this information to identify critical requirements for the case are. Furthermore this objective is necessary for the main objective of the research since a case area is needed for the assessment. The outcome of this objective is presented in chapter 5 – *Case study*

1.4.3 Objective 3
Analyze and explore the quality of the open energy dataset, and the current state of the case area in general

The third objective is to compare the selected case area with the contextual and theoretical background. It elaborates on which similarities and contradiction can be found between the case are and the theory. The following research questions are formulated to achieve the objective.

Q1 – What is the current situation regarding electricity production and consumption?
Q2 – Can service areas be identified for the technical buildings (transformers)?
Q3 – How can the electricity network in the case area be conceptualized?
Q3 – Which requirements have to be met to become 100% renewable (and locally produced)

The first research question of this objective has the same contextual nature as the first objective in general. The second research question aims on finding service areas for the technical buildings (transformers) in the region. This is a necessary step in order to link the consumption points to the origin of electricity in the network. The third research question tries to identify how the actual existing network can be conceptualized. This conceptualization will then be compared with the previously made concept of the electricity network (RQ1.2). At last this objective will identify a list of criteria for an energy transition scenario in the region. It takes into account factors such as the population and the local electricity consumption. This objective is the first step of the actual Open Asset data assessment upon the electricity network in which the content and quality of the data is reviewed. Most of this objective can be found in chapter 6 – *Results.*

1.4.4 Objective 4
Assessing the Open Asset dataset regarding the set requirements for an energy transition scenario

In this fourth and last objective an actual energy transition scenario is tried to be implemented using the open electricity network dataset. The requirements necessary for a transition were already set by the previous objective and will now be tried to model with the dataset. The following research questions are formulated to support this objective.

Q1 – Which rooftops are suitable for solar energy production?
Q2 – Which areas are suitable for wind energy production?
Q3 – How to deal with peaks in electricity consumption or production?
Q4 – What constraints and limitations does the data give?

The first two research questions will be answered with other open data sets like the surface models (AHN) and topographical data (BGT). By making use of the provided open energy data and the theoretical information two suitability analyses will be performed to identify the best locations for electricity production. In addition to that a reflection on the quality of the suitability analyses will be done. The third research question explains how peaks in production and consumption can be mitigated. At last this objective sets out the constraints and limitations that have been identified in the open energy network dataset. In this objective a large part of the actual Open Asset data assessment is taking place from the electricity production point of view.

1.4.5 Objectives and questions overview

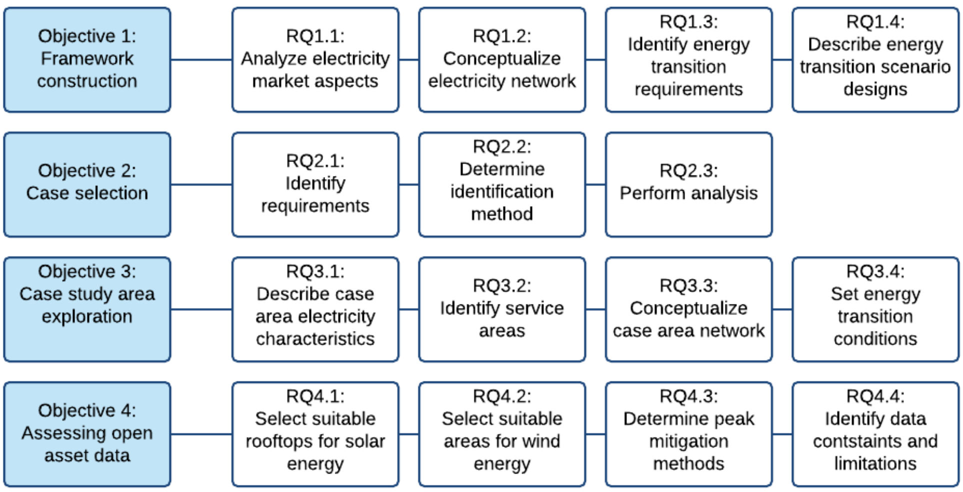

Figure 1.1 Overview of all objectives and related research questions

1.5 Constraints and Assumptions

In this research several constraints and assumptions have been made to simplify complex phenomena or to estimate or predict possible changes in the network.

Constraints

Only buildings that have their own electricity meter or meter box are taken into account in the suitability analysis for solar energy.

In order to make sure that the proposed solar panels can actually be connected to the household and the electricity grid itself it is important to make sure that the building the solar panels will be put on top has its own electricity meter. This is necessary to make sure that it is traceable where the electricity is put into the system exactly.

Only the open network dataset provided by Enexis will be used.

Since the main goal of this research is to assess this open energy dataset this research will only focus on the information that this particular layer provides. No other network data for the same region will be used.

Since the main goal of this research is to assess an open dataset, factors such as day/night, seasons, time-planning, costs and future prediction are ignored for the transition scenario design.

Numerous interesting variables can be encompassed in the energy transition scenario design. Among these are spatial, temporal and cultural factors. However, due to the fact that this research aims to assess the network. These variables have been ignored and only a static moment in time is used for the transition scenario design.

Assumptions

The open energy network dataset provided by Enexis is accurate and complete. Power flow is expected between cables that can be connected with each other.

The Open Asset dataset of Enexis consists of thousands of polylines resembling cables with different voltage values. The attribute table of the lines does not give information about the connectivity with other cables, however when constructing the network a snapping value is used to connect all cables given by the dataset. This is done to construct a working network, however, connecting cables using a snapping value does not guarantee the cables were connected in the first place it is merely an estimation of which cables are most likely connected.

All cables that have, according to the attribute table, no voltage or that are 'not functional' are ignored in the analyses.

Due to the fact that for some reason these cables are no longer used or this data is missing in the attribute table, they have been excluded from further analysis. This is done to avoid working with too many cables that are no longer in use or not even connected anymore. For a conceptual model this is not a problem, but in the real world it is a serious item.

Linkages between networks of other operators are not in this dataset and are therefore regarded as nonexistent.

Interconnecting electricity cables might exist between different net operators. However, the assessed open data set contains only the network of Enexis. This means there is no information about this interconnectivity. Therefore it is assumed that these connections do not exist to simplify possible complexity.

1.6 Report structure

This research report continues in chapter two by presenting the methodology in which the various used methods are used will be explained. Methods such as literature reviewing, secondary data analyses and the various spatial analyses as performed by mainly using ArcGIS (ESRI, 2017) will be explained in this chapter.

The third chapter contains the contextual framework. In this chapter the background and context of the research are presented. This is done to construct a framework of facts about electricity in general and the production and consumption of it in the Netherlands. The fourth chapter is the theoretical framework. In this chapter the main theories are explained. Among these are for example the smart grid system and energy transitions. The fifth chapter consists of the case study and in the sixth chapter the results of the exploration of the scenario will be shown.

Finally the conclusions are presented in chapter seven, along with a discussion and recommendations. This discussion has an internal part, reflecting the thesis process and quality. Besides that it also has an external part in which the outcome of the thesis is reflected in regard to the academic and social context. The chapter finishes with recommendations for further research.

1.7 Flow diagram

Figure 1.2 shows the linkages between the independent research questions, the objectives and the main goals of the research.

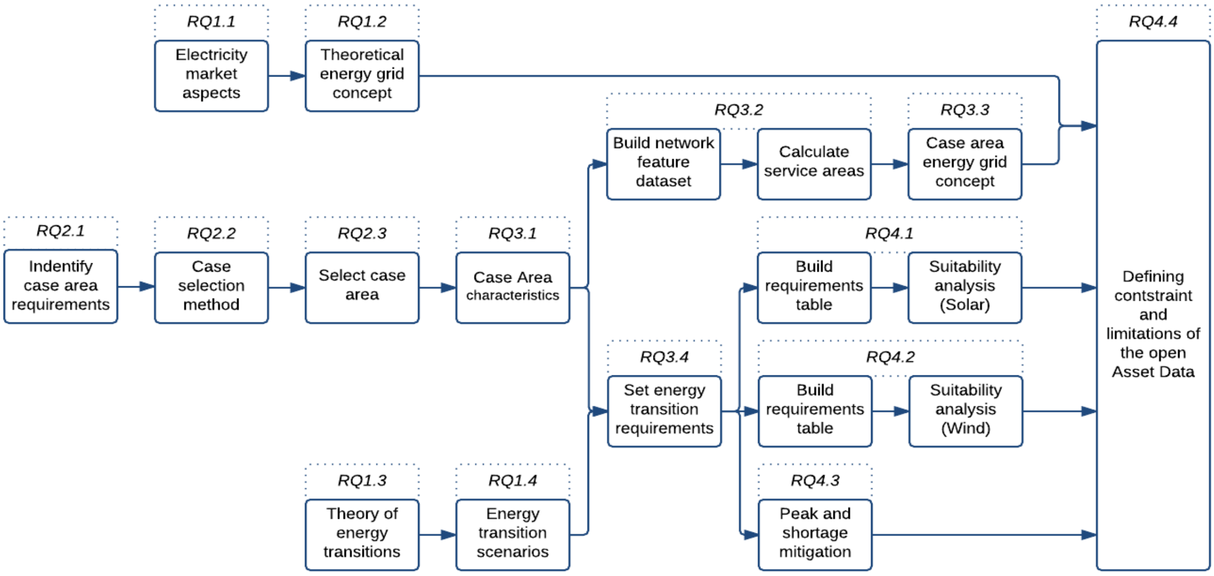

Figure 1.2 Diagram of all linkages between the independent research questions

2

METHODOLOGY

2. Methodology

In this chapter the various methods that have been used in this research will be discussed. In the first part of the chapter the emphasis will be on the methods that have been used in constructing the contextual and theoretical background. These comprise both various literature studies as well as secondary data analyses. In the second part the analyses that have been done with ArcGIS will be explained and discussed. The ethical aspects regarding academic research can be found in appendix III.

2.1 Literature study

The first method that has been used in this research is a literature study. This method makes use of academic sources such as articles from journals or books. The aim of a literature review is to collect information about the topic. In this research the literature study has focused on several topics that have been covered in the Theoretical Framework. Among these are; smart grids, smart metering, smart energy and energy transitions. Multiple academic sources have been used per topic in order to create an elaborate and simultaneously critical view upon the theory.

A literature study in general aims to a build a strong foundation or base of knowledge to build arguments upon (Clifford and Valentine, 2013). Furthermore, it establishes a better understanding of the topic in general; this enhances the creating of a context in which the research will be embedded (Blaxter, Hughes and Tight, 2010). In addition to that, a literature study aims to find a gap in the academic literature that needs to be researched and addressed (Blaxter et al., 2010; Clifford and Valentine, 2013). At last it is important to increase the researcher's personal knowledge regarding the topic, this helps to build a critical attitude towards the literature, input for new ideas and a broader perspective in general (Blaxter et al., 2010). Kneale's (2011) method of reading has been used in this research. This involves quick scanning of abstracts, summaries and conclusions before reading the entire source. This method saves time and is useful for determining which sources are of interest.

RQ2.1, '*How are electricity networks conceptualized in literature?*' has been answered with this method. From academic literature, news websites, blogs and energy websites models have been reviewed and compared to identify common characteristics in order to conceptualize the electricity network. In addition to that also the research questions about the energy transition and how it has been designed for other regions have been answered with a literature study.

The energy transition scenario that has been shaped for the case study in this research is also based on a literature review. By reviewing energy transition scenarios of 7 countries, an energy transition scenario has been designed that fits the case area the best.

2.2 Secondary data analysis

Secondary data sources have been used to collect information. For this research it was primarily data from the Statistics Netherlands about population and electricity production and consumption. Information about the electricity production and consumption amounts has been derived from Statistics Netherlands. This also accounts for RQ3.1, '*What is the current situations regarding electricity production and consumption*', this research question relates to the case area, Statistics Netherlands has data on both neighborhood and district level.

2.2.1 AHN (Actueel Hoogtebestand Nederland)

This dataset is a raster layer that contains height information of the entire Netherlands. Currently there are 2 finished versions, the AHN1 and the AHN2. The AHN3 is not yet available for the entire Netherlands. The raster cell size is of the used AHN2 data layer is 50cm by 50cm and the height is measured in meters (AHN, 2017). This dataset has been used for the suitability analysis for solar energy.

2.2.2 BAG (Basisregistraties Adressen en Gebouwen)

This dataset contains all the official 2D footprints of buildings and constructions (Kadaster, 2017a). This dataset is monitored by the Dutch cadaster (Kadaster). For the suitability analyses for solar energy this layer has been used since one of the requirements is that the solar panels should be placed on rooftops.

2.2.3 BGT (Basisregistratie Grootschalige Topografie)

For the suitability analyses presented in chapter 6 – *Results* data of the BGT has been used. This dataset is monitored by the Dutch Government and gets updated every week (Kadaster, 2017b). The BGT is a dataset that contains all large topographical phenomena in the Netherlands. Among these are for example roads, waterways, railroad, airports and all related supporting facilities around them (Overheid, 2017). This data has been used in order to identify suitable and unsuitable spots for wind energy farming.

2.3 GIS analyses

In order to assess the Open Asset data various GIS analyses and tools have been used in order to prepare, model and asses the data. The first step was to select a smaller part of the dataset to work with. The entire dataset is roughly 4GB and takes much time to quickly browse or scan through. In addition to that doing analyses with a dataset this size takes a lot of time too. Finally the complexity of the network is less when looking on a small scale, instead of taking the entire network.

Whenever analyses with GIS are done, the first step was to set up a requirements table. A requirements table helps to structure the necessary data and preparation in a well-arranged way (Harder, Ormsby and Balstrøm, 2011). For both the site selection as the transition scenario analyses requirements tables have been constructed to order the process.

Figure 2.1 is a cut out version of the larger one presented in section 1.7 – *Flow diagram*. It shows the research questions and steps related to the GIS analyses.

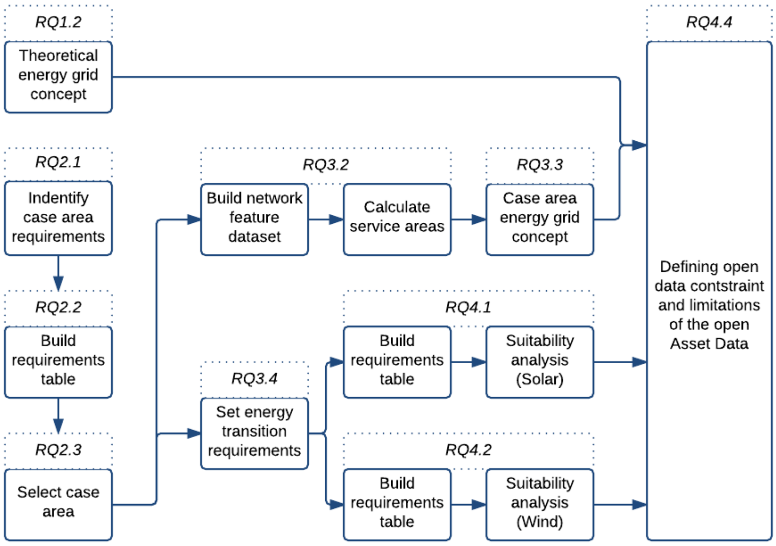

Figure 2.1 Research question and steps related to the GIS analyses

2.3.1 Case selection

In the process of selecting the case a list of criteria has been made first. These criteria can be found in chapter 5 – *Case study*. With tools such as calculating service areas and finding network boundaries a case area was selected. The exact process is described in chapter 5 – *Case study*.

2.3.2 Transition scenario workout

In order to work out the energy transition scenario several adjustments to the Open Asset datasets have to be made. In addition to that the previously mentioned dataset of AHN, BAG, and BGT are necessary for calculation the best spots for electricity production facilities.

Network creation and service areas

In order to assess the dataset provided by Enexis a network has to be created of the polylines in the dataset have to be checked on connectivity and connected where needed. By using the ArcMap network module the network will be created by importing relevant data into a feature dataset. From this feature dataset network can be constructed. A feature dataset contains typically nodes and edges. The edges resemble the cable lines underground and nodes are created on all points where edges are connected. Network tools make use of these rules when modelling.

The distribution boxes and connection boxes often cause cuts in the network while it is expected to be a place where the power does not stop, but just is divided over more or other cables. To tackle this issue the distribution box polygon were converted to polylines and added to the network. This conversion is made visible in figures 2.2 and 2.3

Figure 2.2 original data

Figure 2.3 modified data

This conversion is necessary in order to keep the network functional, this means that the simulated transport of electricity from one location to another does not stop everywhere

where such a box appears. However, it also has downsides since it isnt exactly sure whát happens inside the distribution box with the cables. Sometimes many cables all come together. These are now all joint together on the outline of the distribution box. It could have been the case that not all these cables are on the same network. This is not a very big issue for the calculation of service area's. However it is an issue when trying to identify boxes that might be at risk due to too high power voltages. Since this can be a unique situation for all of the boxes, it has decided that they are all converted and linked to the network.

Other settings for the network building were; switching on the 'create junction' in order to make sure that every line that was connected with another line would make a new junction and that electrical current would be able to split at certain points. 'Connectivity to any vertex'was also switched on. Whitout switching this on the network would stop at various points because of small errors in the data. Sometimes vertices would share the exact same coordinate of their start of end point, but they would still not connect. In order to solve this all vertices that would 'touch'eachother were connected.

This last setting was necessary because otherwise the network would be very limited and many parts would have been excluded from the network. However, connecting on every vertex also has its downsides. Some of these vertices might not have been connected in the real world and are now connected in the model. This distorts the reliability of the network. Direction description in the network build tool have been skipped due to the fact that electricity does not have a real 'direction', there is a voltage on the network or there is not and it can always go in both directions depending on the difference in voltage.

2.4 Suitability analyses

After the network was constructed some suitability analyses have been done to see where which electricity production facilities could be placed. This was done with a multi criteria analysis for finding the best suitable spot. This approach takes multiple factors into account and weights them to see which area is best suited. This approach is also called 'multi-criteria decision making'. The principal of such an approach is to condense complex problems with multiple criteria (Charabi and Gastli, 2011, p.2555). Among these criteria are factor such as slope, aspect, solar radiation or residential areas (El Baroudy, 2016).

A multi-criteria decision making (or MCDM) process can be done with ESRI ArcMap. The outcome of such analyses results in maps that can improve dicisionmaking in general (Heywood, Cornelius and Carver, 2002, p.155). Within ArcMap values or weights can be added to the individual layers to make them more effective in the process. In addition to that some layers can be put in as a boolean value, resulting in a binairy division of suitable and unsuitable within one layer. An example of such a boolean value is highways, railroads or lakes. These are in most case not meant to be removed in order to construct something.

2.5 Software

Apart from the word processing program Microsoft Office Word, three other programs have been used in this research. The first one is Microsoft Excel, the second one is ESRI ArcMap and the third one is LucidChart. Both programs are shortly discussed below.

2.5.1 Microsoft Office Excel

Two datasets of the Open Asset data from Enexis are Excel spreadsheets as well. These contain metadata about the attributes and objects in the shapefiles. Apart from this dataset Enexis also provides information about the electricity consumption of all households in their catchment area. This data is also provided in an Excel spreadsheet and is on zip code level.

2.5.2 ESRI ArcMap

In this research ArcMap has been used to do the data assessment. Various tools and options within the program have been used to explore the data and its capabilities. The license for this software package is provided by the University of Utrecht and activated through the VPN connection with the university.

2.5.3 LucidChart

For all visualizations and conceptualizations other than maps, charts and graphs; LucidChart has been used. LucidChart is an online program that enables the user to make models and figures. It encompasses the ability to insert pictures, symbols and icons. Furthermore the software is able to draw lines, arrows and various shapes. Especially for the conceptualization of the electricity grid this program has been used.

2.6 Data quality

In scientific research it is very important to guarantee the quality of the data that has been used. A higher quality of data gives higher quality of results and makes the research more valuable. Data quality can be divided into eight different components; validity, objectivity, generalizability, reliability, utility, relevance, completeness and integrity (Radhakrishna et al., 2012). The eight different components of data quality are visualized in figure 2.4.

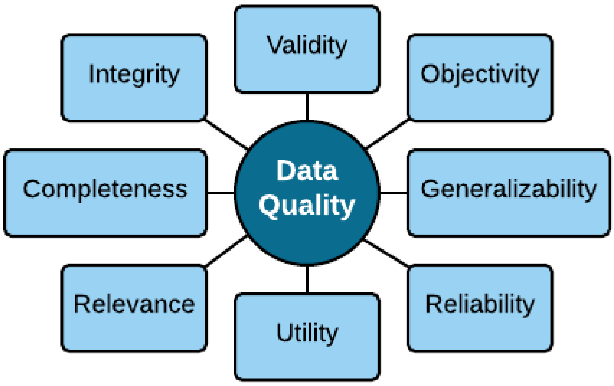

Figure 2.4 The eight componentes of data quality (Radhakrishna et al., 2012)

Not all aspects of data quality are important in every research. This is dependent on the goal of the research, the data that is available and the purpose of the research. In medical studies different aspects are more important than in social studies for example. All aspects and their relevance in this research are discussed below. The eight components of data quality have primarily been used to check the quality of all sources used in this research. Additionally the assessment of the open asset dataset follows some of these quality points.

2.6.1 Validity

Validity stands for the closeness between the provided values and the actual values according to the Organization for Economic Co-operation and development (OECD) (2003). Validity of data can be tested by going into the field and calculating or measuring the values to compare them with the provided data, or by comparing them to other existing datasets (Guba and Lincoln, 1981). In this research the validity of the datasets has not been tested. The four main datasets Enexis Open Asset data, AHN, BAG and data from the Statistics Netherlands are all very large datasets that are gathered and monitored by large and professional companies or public bodies. Therefore it has been assumed that the validity of the data used in this research is sufficient.

2.6.2 Objectivity

Besides validity also the objectivity of data is important. In this context objectivity means that the all the data that has been used and the conclusions drawn from them are objectively made. This also includes conclusions from other papers that have been used for the literature review. It is important in academic research that only sources are used with a high objectivity to avoid working with biased results or conclusions (Guba and Lincoln, 1981; Radhakrishna et al., 2012). In case of this research most of the literature that has been used is derived from the website sciencedirect.com this website includes some of the highest valued journals. In addition to that the website is recommended to be used by the University of Utrecht for providing high quality data. In some cases in this research data with a much lower objectivity has been used. For example in the construction of the conceptual electricity grid. However due to the high amount of sources used to validate the data, the sources were good enough to use to make a conclusion.

2.6.3 Generalizability

In academic generalization are often made; case studies are conducted with the aim to draw conclusion over a bigger area or population. In order to do so it is important that the data that has been used in the case is generalizable, this means that both the case data and the data of the whole area or population share the same key variables (Radhakrishna and Doamekpor, 2008; Radhakrishna et al., 2012). In this research a case area has been used to study to decrease the complexity of the network. In addition to that, the case area only accounts a middle and low voltage network neglecting the high voltage network. For these reasons the case area might not be perfect for generalizing, however the case area is interesting for a data assessment.

2.6.4 Reliability

The reliability of the data refers to the degree of which the measurements that are done in the research are comparable and similar (Centers for Disease Control and Prevention, 2009). Data reliability is an important component when doing statistical studies. For statistical test it is important that the sample size is big enough. Reliability is therefore important in quantitative research and is less an issue when doing qualitative research. In this research no statistical tests were done. However some statements and arguments are built upon multiple sources. This increases the reliability of the conclusions as well.

2.6.5 Utility

The utility component of data quality refers to the aspect of timeliness, accessibility and punctuality. Sound research requires a consistent data collection and storage (Radhakrishna et al., 2012) In addition to that it is important that conclusions and key information can be disseminated towards key stakeholders. In this case the research is a master thesis that will only be published within the University. Even though the topic serve a social and academic skill, its purpose is a learning goal and therefore the actual utility is low of a master thesis. In exceptional cases a master thesis leads to an actual article in a journal.

2.6.6 Relevance

The relevance of research and the data that has been used is important (Organization for Economic Co-operation and Development, 2003; Vale, 2010). A research that has been conducted without relevance or with data that is not relevant is worthless. In order to do a relevant research it is important to find a connection between academic relevance and a social relevance. In this research the relevance of the topic is derived from a public problem (over production of local electricity). This has led to problems and is therefore socially relevant. The academic relevance is the ongoing debate about open data and open data quality, therefore this research assesses an open dataset. The dataset that has been used is from 2015 and therefore still very relevant to use. The other datasets that have been used (AHN and BAG) are both up to date as well. Most of the literature sources are those from the last couple of years.

2.6.7 Completeness

When working with qualitative or quantitative data it is important that this data is as complete as possible. In a spatial context this means that every key variable that is measured is measured and counted for the entire region that has been studied. It does not make sense to study a variable that has only been measured in half the region since the incompleteness of the data will affect the results and conclusions. In case of this research the Open Asset dataset of Enexis does not cover the entire Netherlands but roughly five provinces. A small area right next to the case study is not covered by Enexis and therefore data about that region is missing. This affected the case area, since it was impossible to guarantee that there would be no electricity grid connections between the case area and a part of the municipality of Almelo. However, for most of the assessment this was not issue. Only for the calculation of service areas this could have distorted the output. This missing of data was also mentioned in the section 1.5 – *Assumptions and constraints*.

2.6.8 Integrity

The integrity of data refers to the accuracy and consistency of the data. It furthermore refers to the maintenance of the data (Boritz, 2011). By minimizing error in the process of data collection, modification and analyzation the integrity of data van be ensured (Centers for Disease Control and Prevention, 2009). In this research the amount of errors in the data processing have been mitigated by constantly comparing the results before and after each step. However, even though the Enexis Open Asset dataset is quite accurate small details in the data are missing to make sure that parts that seem connected are really connected. This affects the integrity of the data since assumptions had to be made about how certain cables and boxes were connected. This also affects the outcome of the conclusions of the study.

2.7 In conclusion

In this chapter the methodology of the research has been described. In addition to that the main methods of research and analyses, as well as the main dataset, have been discussed. In this research mainly three research methods are used and four different datasets. Ethical aspects of research are mentioned in appendix III.

3

CONTEXTUAL FRAMEWORK

3. Contextual framework

In this chapter the context and background information regarding in this research is presented. This is mainly about electricity in general, the electricity grid and how electricity is produced and consumed in the Netherlands. It is meant to serve as a chapter in which facts and figures are presented to give background information that is necessary to understand in order to work with the Open Asset dataset or to understand the topic in general.

3.1 Electricity

Electricity can be regarded as the backbone of the modern day society in terms of a power source (Jones, 1991). It can be used to heat or cool objects or to create motion. Electricity is relatively easy to store and using it does not produce any negative gases or residue like other energy sources do. The production however often produces pollution chemicals and gasses. In this section some of the key aspects of electricity and electrical currents are explained since these are important to understand in order to effectively identify requirements for energy transitions or suitable electricity production facilities.

3.1.1 Watts, voltages, amperes and resistance

Watt is the unit of power and is named after the Scottish scientist James Watt. One Watt equals 1 joule per second and the unit is used to quantify the rate of energy transfer (International Bureau of Weights and Measures, 2006). In addition to that Watt equals Volts * Amperes in a circuit. Watts are often used on electrical devices to show the amount of Watts or joules the appliance 'consumes' when fully functioning. For example, a light bulb can be 75W while a microwave is 1000W. Electricity can be used to warm or cool things, or to activate motion on objects. Watt-hour is often used to indicate how many Watts an appliance consumes on an hourly rate. The formula for this is Watt x Hours = Watt-Hours. The average yearly electricity consumption in the Netherlands per household is 3,000 – 3,500 MWh (Statistics Netherlands, 2016c)

Volt is the unit of electric potential or potential difference in a circuit. It can also be described as the amount of 'pressure' there is on the free electrons in the circuit. Volts can only 'press' the amperes through a wire when there is a difference in voltage between positive and the negative side of the cable. In a small circuit with a battery free electrons are 'pushed' out by the volt in the battery as much as they are 'drawn' from the 'empty' side of the battery. This causes the free neutrons to flow over the wire. A battery is empty when the voltage on the positive and negative side is equal. In the Netherlands Volt is often used to indicate the amount of electricity that is being transported, this is strictly not true since voltage only encompasses the pressure on the electricity. Sockets in the wall in the Netherlands are typically 220V. In addition to that the electricity grid in the Netherlands is divided in three levels. The high voltage network (typically 380KV to 110KV), the middle voltage network (50KV to 3KV) and the low voltage network meant for electricity distribution between residential, retail and (small) industry. This low voltage network is 400V, for so called street furniture (bus stops, commercial signs and road signs) a special 220V network is used (Enexis Open Asset Data, 2016).
Ampère is the unit of the electric current itself and is considered as one of the base seven units

of measurements. One ampere represents one coulomb of electrical charge moving pas a point in one second. Phone batteries are typically expressed in amperes, for example 2,100mah. This means the battery has a capacity of 2,100milli-ampere-hour. This means for example that, according to the previous paragraphs and formulas the battery can give 21 hours of 100milli-ampere or 10 hours of 210milli-ampere.

Ohm stands for the electric resistance in a circuit. It is measured when there is a constant difference of 1 volt between the positive and the negative side of the power source. In an altering current system the electrical impedance is measured in ohms as well. The amount of ohm can be calculated by dividing the volts by the amount of amperes.

3.1.2 Altering current and direct current

Electrical current can be transported over wired in two different ways. The first is altering current, where the electrical current is transported using multiple cables or lines that interchange in electricity supply. The direct current uses only one cable with a constant electrical current supply (Pierri et al., 2017).

Altering current is mostly used in the transportation of electricity from the source of production to the consuming parties. Cascading the power to lower voltages is transformers can be done with altering current. Altering current often requires three cables that switch rapidly in electricity discharge. A set of (three) cables represents one electric circuit. Electricity poles often carry one or more electric circuits. Sockets in the wall also provide altering current. For most appliances such as televisions, refrigerators or vacuum cleaners this is right electricity source to use. However, for appliances with internal batteries direct current is preferred. Therefore laptops, mobile phones and other chargers always have an adapter which changes the altering current into a much lower voltage direct current.

Direct current requires only a single cable and the amperes in the cable are pushed at a constant pace. These circuits are used by batteries that can only provide a direct current power flow. Solar cells and dynamos for example generate direct current electricity. With the use of inverters this current can be changed to altering. The use of high voltage direct current electricity transportation is relatively new and is increasingly used. A HVDC system is less expensive to build and has a lower electrical loss (Pierri et al., 2017).

3.1.3 Electricity production and storage

Electricity can be produced in various ways. Some of these require fuels to be burned in order to generate electricity. This is the case in coal or gas plants, where the coal and gas are used to convert water into steam to create electricity. These fuels are regarded as fossil fuels since they can get depleted and will not be able to recover itself in a short period of time. Another type of electricity production is with atom splitting in nuclear reactors, this releases large amounts of energy; however the residue created by this method will be radioactive for thousands of years. The third method is using renewable sources, such as wind, water, solar or biomass. Often these sources have a good environmental impact; however burning biomass still releases large amounts of CO_2 into the atmosphere. Electricity is always produced with direct current but can be inverted to altering current with specially designed transformers.

The storage of electricity is impossible; however electricity can be used to store energy in other forms. This can be done by storing energy in chemicals for example. This is what happens in most of the batteries, where the positively charged electrons are separated from the negatively charged. A second method of energy storage is bringing water back into a dam that functions as a power plant using hydro energy. A surplus of electricity on the grid can be used to pump water back into dam lakes to store the potential energy, which can later be used to generate electricity by the generators inside the dam. This process is currently taking place in the Netherlands.

3.1.4 Central and decentral electricity production

The production of electricity is often divided into two different types. The first type is central produced electricity. This means that the electricity is produced at a very high scale and is directly linked to the high voltage network. This accounts for all gas, coal and nuclear plants in the Netherlands. Large hydro power plants abroad are also often centrally producing electricity (Statistics Netherlands, 2015).

Decentral produced electricity, the second type, is electricity production that happens right at the place where it is consumed. Among this type are wind and solar electricity production. These sources of electricity production are often located near the place where the electricity is consumed. Due to the relatively much lower electric potential in these regenerators, the production facilities are often attached to the middle or even low voltage connection lines (Statistics Netherlands, 2015). Section 3.3 – *Electricity production in the Netherlands* further elaborates on these two different types of electricity in the context of the Netherlands.

3.2 Electricity consumption in the Netherlands

In the Netherlands Electricity consumption is measured on various levels. This can be on national scale, per province or on a municipality level. Besides these statistics based on a geographic location Statistics Netherlands also has data about the electricity consumption based on the household size or type.

Since 1960 the amount of households has more than doubled in the Netherlands (+143%) (Statistics Netherlands, 2016b) see figure 3.1. In addition to that the Dutch population has only risen with 48% (Statistics Netherlands, 2016b); this led to the decrease in average household size. It is highly likely that this average household size will decrease further in the near future.

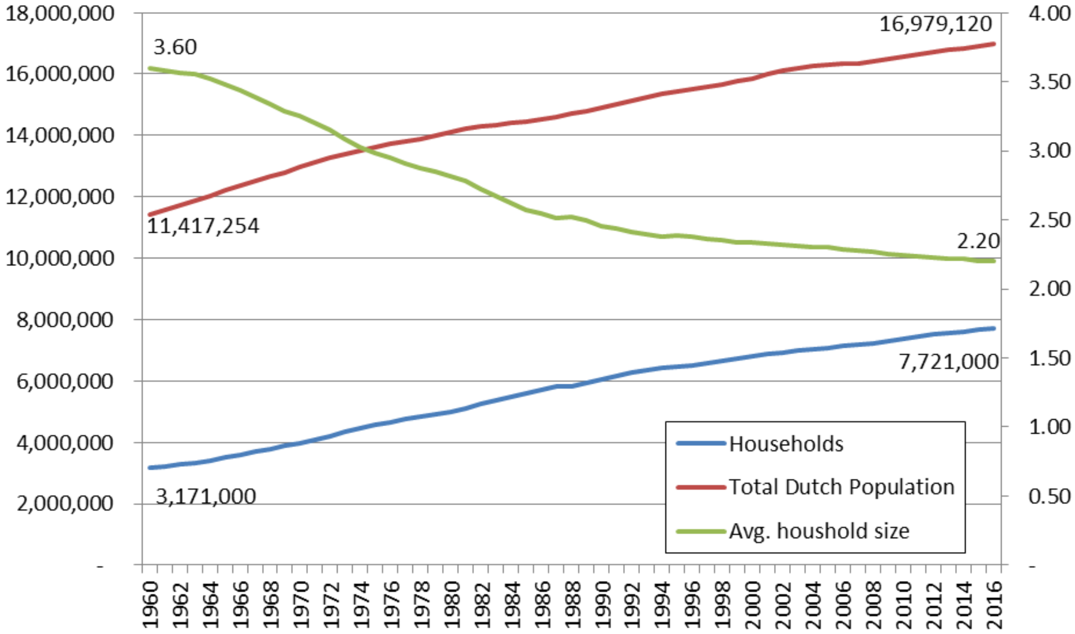

Figure 3.1 Households, total population and the average household size in the Netherlands between 1960 and 2016 (Statistics Netherlands 2016b)

These numbers can be compared with the electricity consumption within the Netherlands. Data of this electricity consumption have been gathered by the Statistics Netherlands since 1975. Figure 3.2 depicts the electricity consumption per household and per person in the Netherlands between 1975 and 2014 (Statistics Netherlands, 2016c). Interestingly the electricity consumption per person has changed little over time; the oil crisis in 1980 caused a mayor dip since the oil prize skyrocketed. Between 1975 and 2014 the electricity consumption per person rose with 10.6%, while the electricity consumption per household rose with 49.5%. However in the last 10 years the change in electricity consumption has been roughly stable. Possible explanations for this are the economic crisis in 2008 (De Volkskrant, 2010), the rise of the electricity price (Statistics Netherlands, 2016e), the increase in energy saving products such as energy-saving lamps and more efficient appliances (Energy Saver, n.d.) or the electricity produced at household level by solar panels.

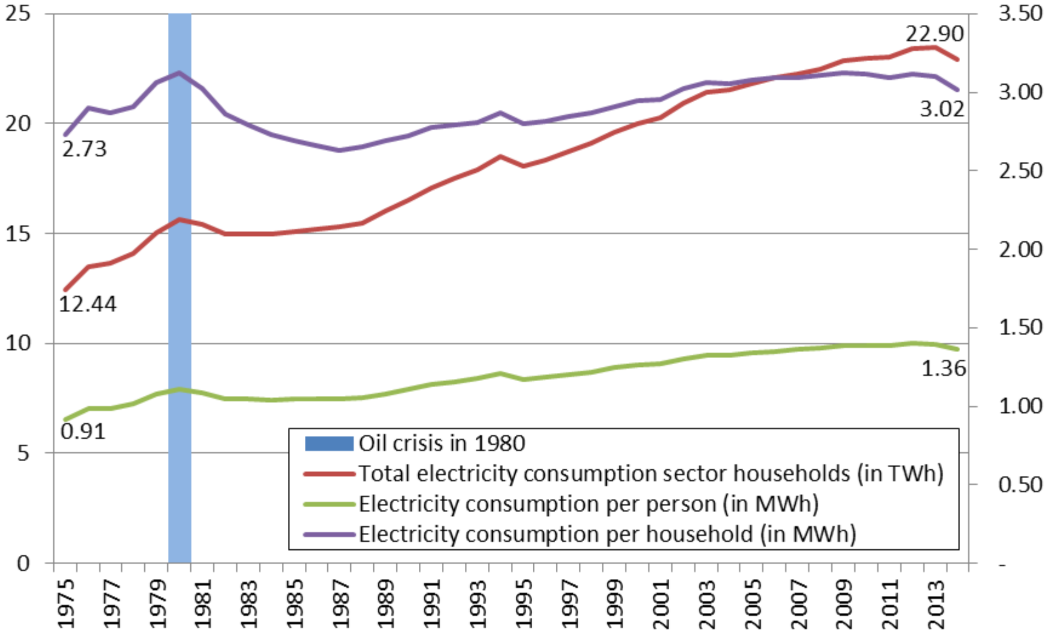

Figure 3.2 Electricity consumption in the Netherlands between 1975 and 2014 (Statistics Netherlands, 2016c)

Besides these electricity saving trends, also energy consuming trends are occuring. Since 2000 the amount of electrical vehicles (EV) has grown exponential, see figure 3.3 (Statistics Netherlands, 2016a). Since January 1, 2013 the amount of EV's has grown with 132% in the Netherlands. It is estimated that an EV consumes around 3 MWh on a yearly basis (Zerauto, 2012), roughly the equivalent of 1 household in 2014 (3.02 MWh). If this trend is going to continue in the upcoming years. It is expected that the electricity consumption will increase too.

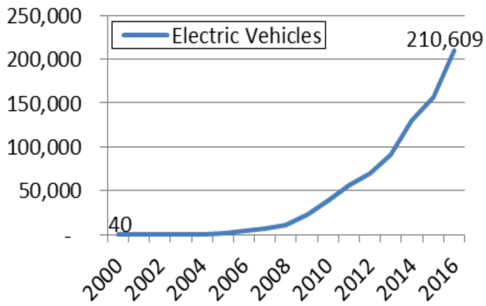

Figure 3.3 Total amount of EV's in the Netherlands (Statistics Netherlands 2016a)

3.3 Electricity production in the Netherlands

In the Netherlands around 87% of the electricity that is consumed is produced within the country itself (Statics Netherlands, 2015). The largest share of this electricity production within the Netherlands comes from the burning of fossil fuels such as gas, coal and oil. In addition to that electricity is generated in the nuclear power plant in Borsele or with renewable sources such as the many windmills around the country, solar panels on rooftops and biomass converters (Statistics Netherlands, 2015).

In the Netherlands electricity is mostly produced central. Around 65% of the production happens in these large power plants. Around 35% of the production takes place on a more decentral level. This share of decentral production has risen fast between 1980 and 2000 after the oil crisis which increased the price for oil rapidly. Figure 3.4 shows the change in central and decentral produced electricity. The dip in total production and the sudden share increase of decentral production of electricity both happen in the same year as the oil crisis (1980) (Statistics Netherlands, 2015)

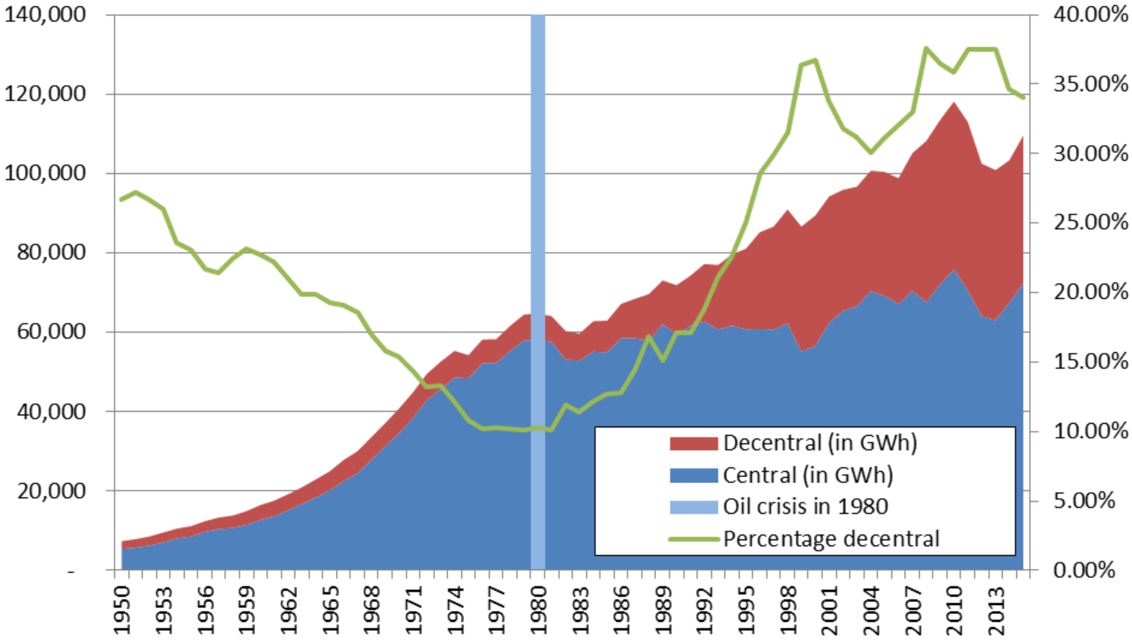

Figure 3.4 Dutch electricity production split out in central and decentrally produced (Statistics Netherlands, 2015)

In 1998 roughly 91% of the electricity produced in the Netherlnads came from fossil fuels. In 2013 this share has dropped to 82%. The share of renewable energy has increased from 2,5% in 1998 to 12% in 2013.

Figure 3.5 shows the increase in electricity production by solar panels in the Netherlands. Between 2010 (88MW) and 2013 (722MW) the total capacity of the solar panels in the Netherlands has increased with 720% (Statistics Netherlands, 2016d). It is expected that the 1GW milestone has been reached mid-2014. The total production electricity by solar panels was in 2013 516GWh (Statistics Netherlands, 2015), which is approximately 0.5% of the total electricity production in 2013. According to Netbeheer Nederland the total power capacity of solar panels has been doubled between 2013 and January 2016 (Schootstra, 2016).

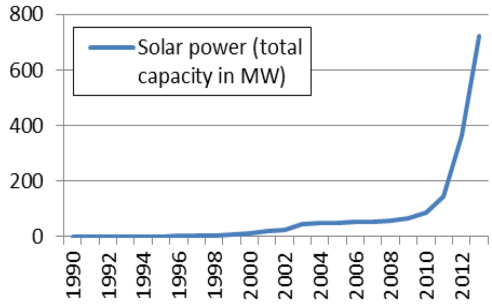

Figure 3.5 Total capacity of electricity production by solar panels in the Netherlands (Statistics Netherlands, 2016d)

However, since not every solar power installation has been officially reported estimations range between 1.500MW and 1.600MW in 2016 (Schootstra, 2016). Holland Solar (2017) speculates that the total amount of electricity from solar panels could be around 2,000-2,200MW at the start of 2017, this is slightly more than 2% of the total electricity production in the Netherlands. Furthermore, due to the decreasing price of solar panels (Carr, 2012) and the increase output of solar panels (Diamandis, 2016) it is highly likely that the amount of solar panels will increase in the future. More information about the working and implementation of solar panels can be found in section 4.6 – *Solar energy.*

The amount electricity that has been created by wind mills has increased since 1998 as well. In 1998 the production of electricity by wind mills was around 640GWh, in 2013 the production has risen to 5,627GWh. This is an increase of almost tenfold. Wind energy contributes to around 50% of the renewable energy production in the Netherlands or 5.5% of the total electricity production (Statistics Netherlands, 2015). In other countries around the world this amount and share are much higher. In Germany for example, in 2015 79,206GWh was produced. This is more than 10% of the country's electricity production (German Ministry of Economic Affairs and Energy, 2016). Denmark has a lower absolute wind energy production of 14,130GWh, but a much higher share of 49% of electricity being produced within the country (Danish Energy Agency, 2014). More information about the working and implementation of wind mills can be found in section 4.7 – *Wind mills.*

3.4 Electricity network in the Netherlands

In the Netherlands the energy network is split out in three different groups; these are the high voltage powerlines, the middle voltage powerlines and the low voltage powerlines. The high voltage lines range between 50kV and 400kV and are mostly above ground attached to transmission towers. In addition to that they are often connected between power plants and distribution substations. The high voltage network also crosses borders. Lines from the Netherlands go to Germany, Belgium, United Kingdom and Norway.

The second type of powerlines is the middle voltage line. These are typically between 1kV and 50kV. Middle voltage lines connect the distribution towers to the local network. In the Netherlands these cables are underground; however in Germany for example these cables are often visible in the streets. The middle voltage network is less interconnected with other local networks. In some cases they are linked, but mostly they serve a certain area. The middle voltage network is connected to the low voltage network through technical buildings.

Technical buildings are often shaped as a cube and made of thick concrete. In these buildings the middle voltages is transferred to a much lower voltage. Depending on the purpose of the power, 230V or 400V networks are used. In the low voltage powerlines a division is made between lines that function as distribution lines, and lines that serve as connection lines. The latter are powerlines that connect the actual residential, commercial and industrial buildings to the network. These buildings are called 'service points' in the dataset (Enexis Open Asset Data, 2016).

4

THEORETICAL FRAMEWORK

4 Theoretical framework

In this chapter the theoretical background of the study is presented. Knowledge in this chapter is mostly based on academic papers and literature. The chapter functions as a foundation to do the actual research on. In this chapter the concept of the energy transition and a conceptualization of the electricity grid are presented. Furthermore it elaborates upon topics such as smart grid and smart metering, renewable energy sources and smart storage solutions. Two types of renewable energy production are worked out in more detail since these form the basis for the energy transition scenario that is presented in chapter 5 – Case study.

4.1 Energy transitions

As shortly described in the problem and context the Netherlands, together with many countries in the world, are facing an energy transition. Every country and even every region can be in a different state of this transition. This transition occurs mainly in two different aspect of the electricity system in the Netherlands. First, the share of decentral produced electricity is increasing; secondly the amount of renewable/sustainable energy is increasing too.

Energy transitions are not something new, the invention of using coal instead of wood, or using nuclear power were transition in the energy system as well (O'Connor, 2009; Rhodes, 2007). These energy transitions used to be long processes that could take up to 50 years (Grin, Rotmans and Schot, 2011; Kern and Rogge, 2016; Markard, Raven and Truffer, 2012). In addition to that an energy transition can be regarded as an interaction that takes place between three different phenomena. These are natural, cultural and technical phenomena in a geographical setting (Bridge et al., 2013). The energy transition the Netherlands and many more countries are currently facing is also one of the most debated challenges of our time according to Faller (2015). Faller argues that one of the core elements of the current transition is the production of renewable sources. Furthermore he mentions that the transition opens a debate between operators, engineers, planners, politicians and the local residents about how to organize this transition (Faller, 2015).

Lienert, Suetterlin and Siegrist (2015) argue that the energy transition can only be accomplished if the current high voltage grid will be expanded to support the change in electricity flow. They add to this that high voltage powerlines also create public opposition; no one wants to live with high voltage lines in their backyard (Lienert et al., 2015). The current energy transition has a big focus on the implantation of renewable sources for energy and electricity. In general the implementation of renewable sources is received positively by the public (Lienert et al., 2015). Worldwide many governments focus on this increase of renewable sources in an attempt to lower the greenhouse gas emissions in order to counteract climate change (Lienert et al., 2015; United Nations, 2010).

As described in both this chapter and in chapter 1 – *Introduction*, the Netherlands focusses on this increase of renewable sources too. The issues that occurred in Belgium and the Netherlands due to the increase of solar energy are in line with the statement of Lienert et al. (2015) that the energy network needs to be increased to support the capacity.

4.1.1 Energy transitions in other countries

In order to identify characteristics of energy transitions scenarios design, seven studies have been reviewed to gain an overview. All these studies are done by research teams with the same goal, an area that is for 100% supplied by renewable energy. The areas that have been studied are Australia (Wright and Hearps, 2010), Finland (Child and Breyer, 2016), Ireland (Connolly et al., 2011), Japan (Lehmann, 2003), New Zealand (Mason, Page and Williamson, 2010), Nigeria (Akura et al., 2017) and Portugal (Krajačić, Duić and Carvalho, 2011)

All studies focus on a transition towards 100% renewable sources. The three main sources for this are wind, water and solar. On a lower scale biomass and geothermal heat conversion are used to generate electricity. For wind power it is always aiming at wind turbines producing electricity. The production of solar energy is divided into two different methods. These are photovoltaic cells to generate electricity or by creating a solar power tower which uses the infra-red light to heat up water.

In addition to that some reports work out one scenario (Australia and Finland for example), while others have designed multiple scenarios (Ireland: 4, Japan: 6 and Portugal: 2). All reports focus on a very detailed time step to monitor the exact electricity consumption and production. In the case of Australia for example the time step of electricity consumption is 30 minutes (Wright and Hearps, 2010).

For the production of electricity the landscape and position on the earth is leading in most studies. New Zealand for example does not include solar power because the relative southern location does not make solar energy very productive. In addition to that, the large country size and remote areas give good chances for wind farming. Furthermore hydro power is also very viable in New Zealand (Mason, Page and Williamson, 2010). In the report for Nigeria solar power and hydro power contribute together for 75% of the energy production, the remaining 25% is divided between wind and biomass (Akura et al., 2017). In the reports of Australia and Finland wind and solar power form the majority of power production with respectively 98% and 70% of the production (Child and Breyer, 2016; Wright and Hearps, 2010). Due to the weather dependency of solar and wind power some reports built in a spare electricity source that can be activated when the supply does not meet the demand.

Most reports do not mention the electricity grid or modification necessary in the grid. However, the Australian report comes with very detailed modification necessary to connect the whole country with each other. In the current situation some provinces in Australia have their own electricity network and are not connected with the rest of the country (Wright and Hearps, 2010). The report about Finland mentions that the network might not be suitable for intensive storage of electricity in electric vehicle batteries (see section 4.5 – *Energy Storage Solutions*) (Child and Breyer, 2016).

To conclude; most report have included much variables such as seasons, day and night and future increase in demand. They have furthermore included a total cost of the transition and a possible time frame for the transition. Wind is often most preferred but also solar power is often mentioned as a big pillar of energy production in the transitions.

4.2 Electricity grid concept

In order to gain better understanding of the electricity grid and the cascading of power, a conceptual model of the electricity grid has been constructed. This concept is visible in figure 4.1. For the construction of this model 11 different power grid concepts have been compared to see what similarities they all have. The images of the eleven grid concepts are in appendix III.

Visible in the concept presented in figure 4.1 are the three levels of voltage in the common electricity network. It furtermore depicts the levels on which a cascade, a downscale of power, occurs. At last the actual connection points are connected to the network. In the lower voltage zone often a 'distribution' and a 'connection' network are visualized. These two networks are connected to each other by distribution transformers. The network as shown in figure 4.1 resembles a (span)tree network.

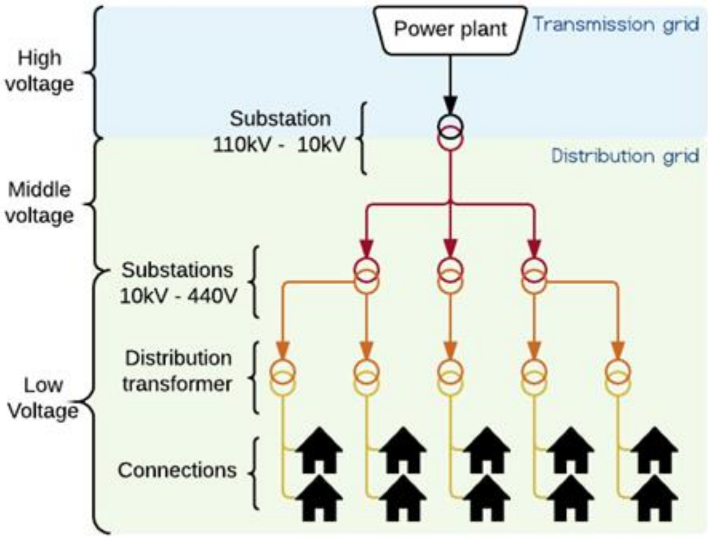

Figure 4.1 The conceptual electricity grid

(sources: Altalink, 2017; DTE Energy, 2017; Eurandom, 2012; Howell et al., 2017; Kökturk and Tokuç, 2017; Lesser, 2014; Martin, 2013; Morvaj et al., 2016; Müller et al., 2017; Wikimedia, 2008; Wikipedia 2017)

4.3 Smart grid and smart metering

As mentioned by Lienert et al. (2015), it is necessary to improve and adjust the exiting electricity network in order to make it support the energy transition. This change should be in the form of increasing the high voltage line network. In addition to that the energy grid should be transformed into a 'smart grid' using 'smart metering' for information exchange. It is of great importance that the energy network is in a very good condition since the human social welfare and well-being are heavily dependent on affordable access to energy (Haas, Watson and Eichhammer, 2008)

The smart grid concept can be defined or explained as self-sufficient systems that are capable of finding solutions to issues in a network or system (Bayindir, Colak, Fulli and Dimirtas, 2016). This smart grid uses web-enabled hardware in order to communicate with itself (Lawrence, Boudreau and Helsen, 2015). However, the Smart Grid system is also very broad in its scope. This makes the potential landscape of standards also very large and complex (International Electrotechnical Commission, 2016). Traditionally the energy system transport energy from the central power plants to the consumers lowering gradually the voltage to make the electricity 'flow' towards the customers (Bayindir et al., 2016), but since more and more energy is produces decentral, and all extra generated electricity will be put back into the system, a smart system is necessary in order to accommodate this. A Smart Grid offers opportunities of monitoring the distributed energy from all producers and all consumers and is capable of interfering when needed (Bayindir et al., 2016). In addition to that a Smart Grid system can reduce the workforce by automating operations and increasing its reliability by decreasing the likelihood of power outages (Sharma and Mohan Saini, 2015).

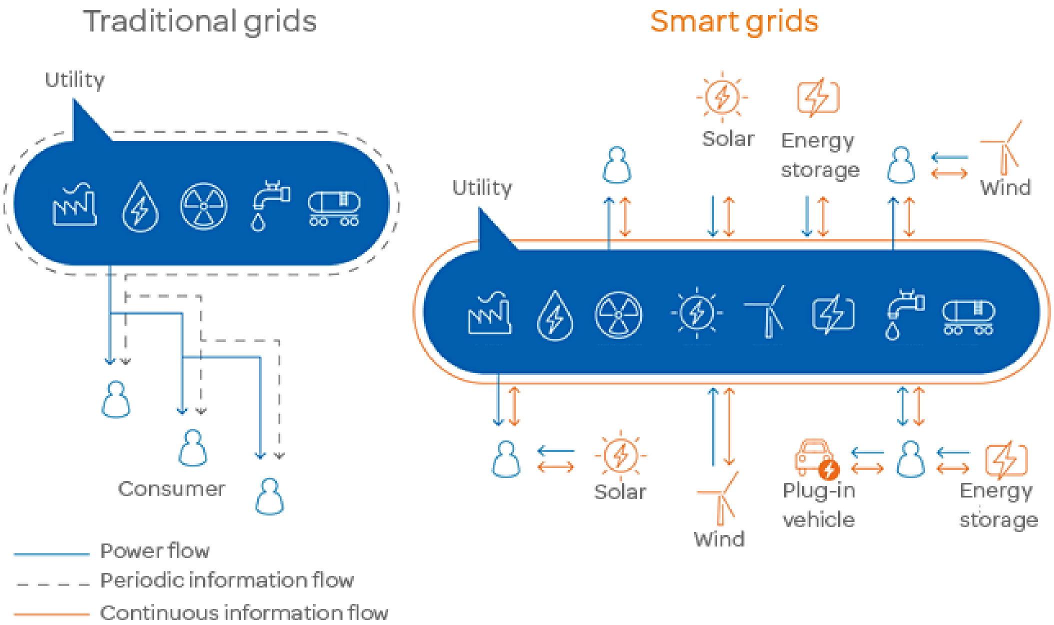

Figure 4.2 A Smart Grid visualized (AT&T, 2016)

Figure 4.2 is a visualization of such a Smart Grid network. Some previously mentioned aspects are visible in the Smart Grid, such as the central and decentral produced solar and wind power. Furthermore it emphasizes on the information exchange in the entire network. Also the electric vehicle is presented in the model. The continuous flow of information as depicted in figure 4.2 could be monitored by making use of Smart Metering. Smart Metering is referred to as the next-generation measurement system for power (Sharma and Mohan Saini, 2015). They add to this that the Smart Metering system will contribute to a more intelligent system with a faster response time.

4.4 Renewable energy (RE)

Renewable energy is energy that is produced by sources that are renewable. It is the opposite from fossil fuels where the sources are depleted after consumption. Examples of renewable sources are, hydropower, wind power, biomass, solar power and geothermal. That a source of electricity production is called renewable does not always mean it is good for the environment and climate. Biomass power is regarded as renewable since the source can replace itself because it consists of vegetation. However, the burning of biomass produces CO_2 just like the burning of coal does. The four other sources of renewable sources are much cleaner in their production of electricity but the construction of them and the extraction of raw materials from the earth have its impact as well.

4.5 Energy storage solutions (ESS)

Most renewable sources are dependent on environmental factors. On a cloudy day the productivity of solar panels is much lower than on sunny days. The same accounts for windmills on days with barely a gust. Hydro power is often relying on rain or melting glacier ice higher upstream. This fluctuation of energy production makes it necessary to great a higher potential production capacity to cover up peaks in demand or dips in supply. Another way to tackle this issue is by storing energy at times overproduction is taking place. Electricity itself is impossible to store, however the energy electricity gives can be converted and stored in various ways.

One way is to store electricity in chemicals in batteries. These batteries can be placed in houses to store electricity surplus on sunny or windy days and give back the energy when needed. Another method is to use the energy to pump water back into a dam. This is what currently happens when there is too much electricity generated in the Netherlands. The surplus in electricity flows through underwater cables towards Norway, where the energy is used to pump water back into a lake. The third method is rather new and not yet in use, but offers potential in the future. Through smart storage in all batteries attached to the network and smart use of this stored energy peaks can be mitigated.

In both the Finnish and Australian energy transition report the use of car batteries was mentioned as a possible solution for a surplus in energy (Wright and Hearps, 2010; Child and Breyer, 2016). Through smart recharging (during the day, when consumption is not the highest, but production of solar energy is) and smart discharging (in the morning and evening when electricity consumption is higher) the car batteries could function all together as a battery. The amount of electric vehicles is growing fast and the potential for this type of energy storage is growing with this.

4.6 Solar energy

Electricity can be generated using the energy from the sun. This can be done in two different ways. The first one makes use of the infra-red radiation of the sun, while the other uses the photons emitted by the sun. Both systems are shortly explained down below.

The suns emitted infra-red light can be used to generate power. This is done by large solar power plants that work with concentrated solar. These power plants consist of a large field full of mirrors all oriented at a tower in the center. This tower functions as a giant pot of water that will be heated up with all the infra-red that gets directed towards the tower. This

The second one is by making use of photo voltaic cells (PV). These are also called solar panels and are often applied to buildings and common on satellites. Photons that are emitted from the sun are cast upon the surface of the solar panels. These photons react with the silicon atoms in the solar panels. This 'frees' neutrons that are attached to the silicon atoms. Due to an artificially created imbalance of neutrons within the panel a 'flow' of charged neutrons is appears. This creates an electrical field across the cell. Due to the fact that silicon functions as both a semi-conductor and an insulator this electrical field is maintained and generates power whenever photons reach the surface of the solar panel. The power produced by this method is direct current and requires a special converter that converts direct current (DC) to an alternating current (AC) in order to be functional in households and companies (Physics, 2014).

In order to optimize the revenue of photo voltaic cells, the cells need to be placed with a specific slope and aspect to maximize the solar irradiation. This slope and aspect differ per country due to the variation in latitude. On the equator a flat solar panel would have the highest revenue, however the further towards the poles, the more tilted the solar panel has to be in order to achieve the highest possible revenue. Besides that, on the northern hemisphere a southern aspect is preferred, while on the southern hemisphere a northern aspect is most efficient. The average production per m^2 in the Netherlands is estimated to be 2,7kWh (KNMI, 1992). This value has been used for the calculation of needed solar roofs in the transition scenario.

4.6.1 Slope

Due to the round surface of the earth, higher latitudes cause a change in inclination of sunlight. To tackle this loss of solar inefficiency solar panels can be tilted. The best of tilt of the solar panel differs per season due to the angle of the earth in relation to the sun. In addition to that, there is no exact line between a good slope and a bad slope. It is a gradual factor which has an optimum. Furthermore the slope and aspect both combine the best surface. A slope of 30° facing north is worse than a slope of 20° facing south for example.

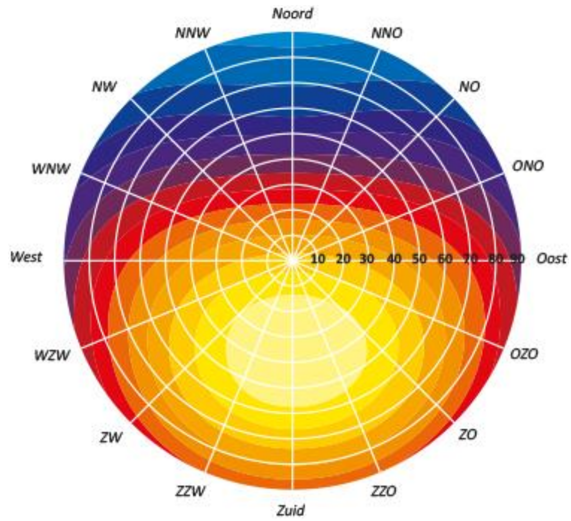

Figure 4.3 Various slope and aspect values combined

Figure 4.3 shows how various slopes and aspects combine certain values, the circles resemble the slope angle and the wind directions the aspect. The yellow field resembles a very high efficiency for solar panels, the more blue the worse. Table 4.1 below shows common slope percentages mentioned by companies, blogs and papers.

When looking at these mentioned values certain common aspects can be found. On average the mentioned slope is around 30 to 35 %. For slope also lower and higher values were mentioned. But then often the 'scope' of aspect becomes narrower. For example, the first source mentioned in table 4.1 is Mansell (2017). The broader the mentioned slope gets, the smaller the bandwidth of the aspects gets and vice versa. This is in line with figure 4.2 above. For this research a slope gradient of 25° to 40° is used to identify suitable rooftops. In chapter 2 – *Methodology* is described how the suitability analyses were performed.

Table 4.1 Slope and aspects values

#	Mentioned slope	Mentioned aspect:	Source
1.	10° to 60°	150° to 210°	Mansell (2017)
	20° to 50°	125° to 225	Mansell (2017)
	20° to 30°	120° to 240°	Mansell (2017)
2.	35°	180°	Siderea (2017)
3.	36°	180°	ZonnepaneelExpert (n.d.)
4.	30°	180°	BTDuurzaam (n.d.)
5.	20° to 30°	180°	Schoenmakers (2017)
6.	20° to 40°	135° to 225°	AllesOverZonnepanelen (2012)
	20° to 50°	158° to 203°	AllesOverZonnepanelen (2012)
7.	30°	-	PureSolar (2013)
	15° to 50°	-	PureSolar (2013)
8.	20° to 50°	-	Fransman (2014)
9.	25° to 40°	160° to 200°	DutchSolarEnergy (2015)
	20° to 45°	140° to 220°	DutchsolarEnergy (2015)
10.	20° to 40°	135° to 225°	SolarPanelInstallations (2011)
	10° to 50°	150° to 210°	SolarPanelInstallations (2011)

4.6.2 Aspect

The second variable that is important for optimizing solar insolation is the aspect of the solar panel. For the northern hemisphere this aspect has to be as southern as possible. For the southern hemisphere this aspect has to be as northern as possible. Aspect is most of the times divided in 360° or in wind directions. Table 4.1 elaborates on the different aspects mentioned by the same sources as the slope gradients. As can be seen, south, or 180° is always preferred. When looking at a broader range of aspect values this is always equally distributed towards the south and west (due to sunrise and sunset). For this research an aspect of 140° to 220° has been used to identify suitable rooftops. A detailed description of the actual method of the suitability analysis can be found in section 2.4 – *Suitability analysis*. The results of this analysis can be found in chapter 6 - *Results*.

4.7 Wind energy

Another method of electricity generation is wind energy. Using the wind for the creation of energy is thousands of years old (Tummala et al., 2016). However, in the past wind was not used to create electricity, but its motion was captured by mills to create motion in objects. This could be in the form of mills that could grind grain, or mills that could pump water out of polders. Since the 20th century wind mills have become a source of electricity. In the early days this electricity was directly used at the place op production, mainly on farms in sparsely populated areas (Redlinger, Anderse and Morthorst, 2002).

Large wind mills that generate electricity are typically around a hundred meters tall and can generate 1MW to 3MW of electricity (Tummala et al., 2016). These windmills are placed decentral near consumption points, as well as in large central wind farm parks. Windmills convert the wind into circular motion, which through various gears speeds up the dynamo inside the wind turbine; this high speed rotation generates electricity. One windmill can provide electricity for up to 4,000 households (Statistics Netherlands, 2016b)

4.7.1 Requirements for wind farms

Wind is mostly common in coastal areas, mountainous and plain areas such as the poles. The rainforests around the equator have only very small amounts of wind. The Netherlands in general offers a good environment in terms of wind for both onshore and offshore wind farming. For the smaller windmills it was important to be present in an open field so it could receive the maximum potential wind in the area. With the newer and much taller windmills even placements in forests is possible. This has been tested in Germany for example (Frangoul, 2017).

Since windmills convert the energy of the wind into electrical energy, the potential wind power decreases behind the wind mill. This phenomenon could affect wind mills that are placed in dense rows. Therefore it is important to make sure a certain amount of distance is applied between several windmills. For many windmills in the Netherlands this distance is around 250meter. However according to Higgens (2013), 640meter was long used as the official distance between wind mills but is no longer the best option. Meyers and Meneveau (2011) argue that a distance of at least 1250 meter is necessary in order to make the wind mills function to their full potential.

4.7.2 Nimby effect of wind mills

With the placement of wind mills strong a NIMBY-effect is present in the Netherlands. NIMBY stands for Not In My BackYard. The placement of 100meter tall wind mills near residential areas has led to many protests since people do not want to see the windmills on the horizon. This is also called horizon pollution. In addition to that the rotation of the blades of wind mills make a low humming sound that is perceived as annoying (RIVM, 2016; RVO, 2016).

Finally the blades can cause the shadows to fall over people their houses or gardens. This is perceived as unwanted as well. Therefore the Dutch government has made regulations regarding these issues. In the case of shadow from the blades a maximum of 20 minutes per day, and 17 days in total has been set as the maximum. This gives a total of 6 hours of blade shadow a year (NWEA, 2016; Rijksdienst voor Ondernemend Nederland, 2016).

5

CASE STUDY

5. Case study

In this chapter the site selection for the data assessment is presented. Previous chapter 3 and 4 has described the contextual and theoretical background regarding electricity and energy transitions. With this knowledge a site will be selected within the Netherlands that will be the subject of an energy transition. The requirements for the energy transition scenario are presented in section 5.5 – Transition requirements

5.1 Requirements and methodology for site selection

According to the conceptual model of the electricity grid as presented in section 4.2 – *Electricity Grid Concept*, it is expected that the high and middle voltage networks both are multi-connected like a mesh network, in which the nodes are connected to multiple other nodes and no hierarchy can be found. The low voltage distribution network contradicts with this in being more organized as a tree network. The last part of the low voltage network is shaped in a bus network type, where the actual houses are connected to a single cable running below the street.

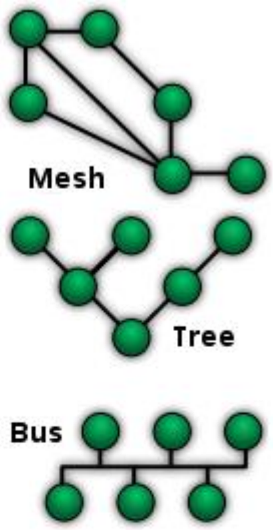

Figure 5.1 Expected network forms

It is important for modelling and doing calculations with a network that the network is closed and isolated. Therefore one of the criteria for selecting the case area is that middle voltage mesh network can be isolated from surrounding middle voltage networks. Another benefit of such an isolated network is that it is easier to see where the electricity flow is coming from.

Other requirements for the case area are that it should be located within the Netherlands and that the Open Asset dataset from Enexis covers the region. Furthermore it is important that the case area is being connected with only 1 high voltage line to minimize a complex network in which multiple inputs are responsible for the power supply. The last requirement is that the middle voltage network in the case are van be isolated from the surrounding areas. This is necessary to define the service areas. All requirements are listed in table 5.1.

Table 5.1 Requirements table for site selection

#	Requirement	Defined	Spatial data	Attribute data	Dataset	Preparation
1	In the Netherlands		Netherlands		Netherlands	Intersect
2	In Enexis service area		Enexis service		Open Dataset	intersect
3	Low complexity of Hv	1 Hv input				
4	Isolated Mv	mesh				

5.2 Site selection

The first three requirements are combined in figure 5.2. The map shows the Netherlands and the service area of Enexis. The blue lines on the map represent the high voltage power cables in the Netherlands. The two black squares on the map indicate where a possible good site is for the data assessment. These two areas both have a single high voltage cable 'entering' the region. This means that that cable is probably responsible for the electricity input for that region.

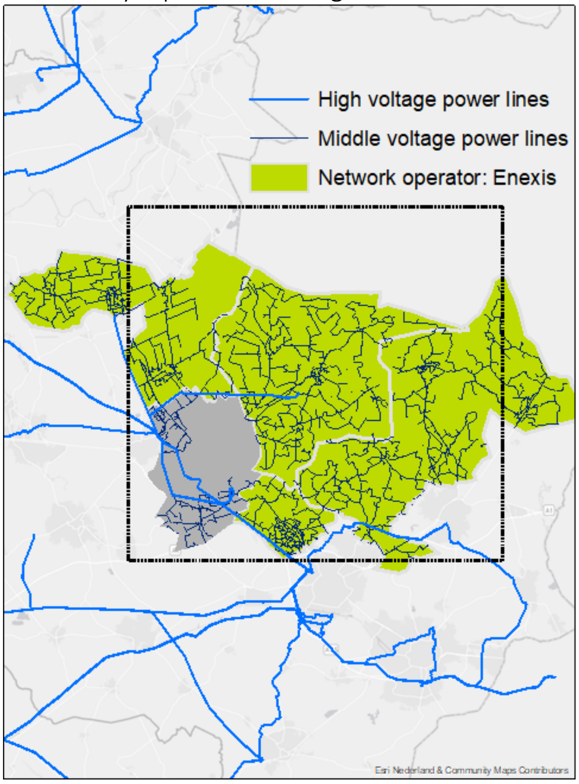

Figure 5.3 Second phase of site selection

Figure 5.4 shows a more detailed version of this case area. The blue dots resemble the technical buildings that seem to be present at every end of the middle voltage lines. The thick blue line resembles the high voltage power cable that enters the region. Small clusters of blue dots are denser populated areas where the power is divided by more technical buildings. The case area is roughly the same size as the municipality of Tubbergen located in the eastern part of Overijssel.

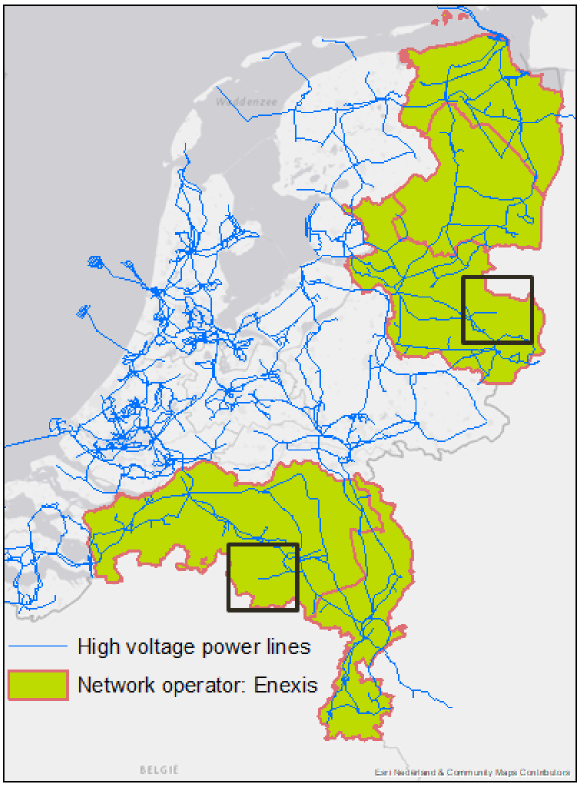

Figure 5.2 Phase one of the site selection

The second step after this was to inspect the two possible regions for the assessment. Figure 5.3 is an zoomed in version of the possible case area in Overijssel. The darker blue lines resemble the middle voltage network. Roughly equal as the grey line that indicates the municipality boundary, an isolated middle voltage network can be recognized.

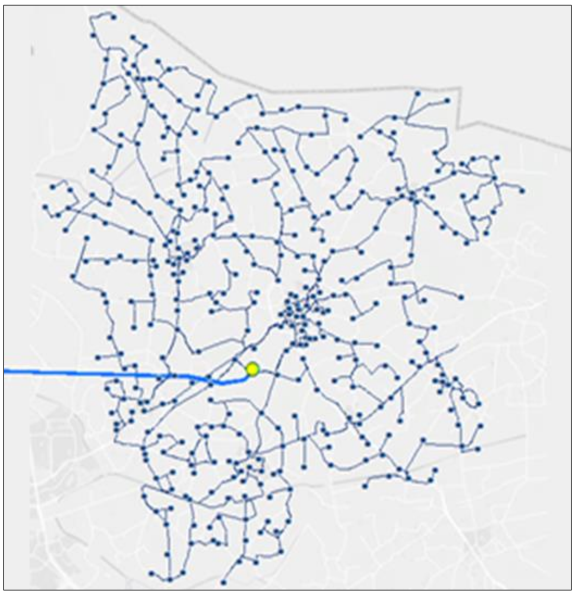

Figure 5.4 More detailed map of the case area

Figure 5.5 represents a further zoomed in version of the electricity network in the case area. In this map the light blue lines resemble the low voltage distribution network. The orange lines are also low voltage but represent the low voltage connection network. The grey and green squares are the smaller distribution boxes that divide the power over more cables. Not visible in this map but every orange line ends in a nodes resembling a service connection point. In figure 5.5 is also visible that the low voltage connection network has the shape of a bus type network.

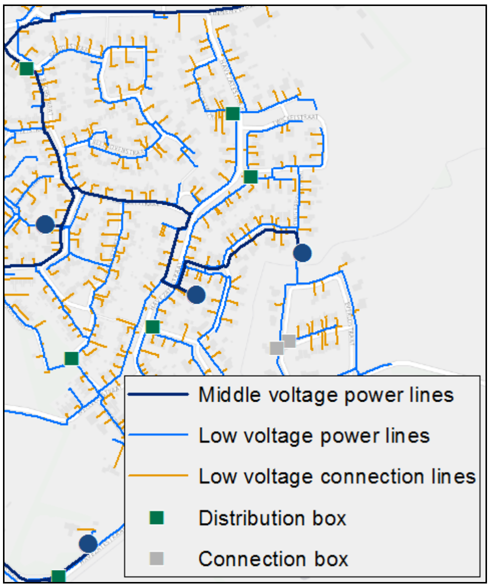

Figure 5.5 Further zoomed in on urban area in the case

5.3 Site characteristics

Not all line features and point features are related to each other in the dataset of Enexis. Figure 5.6 shows all 4 line features and 4 point features and there connection and the 110kV Tubbergen station which is not in the dataset. A green box means that both features can be linked on the map. The figure shows for example that all service points are connected to low voltage connection lines, or that low voltage powerlines can be connected to low voltage connection lines, technical buildings, distribution boxes and connection boxes.

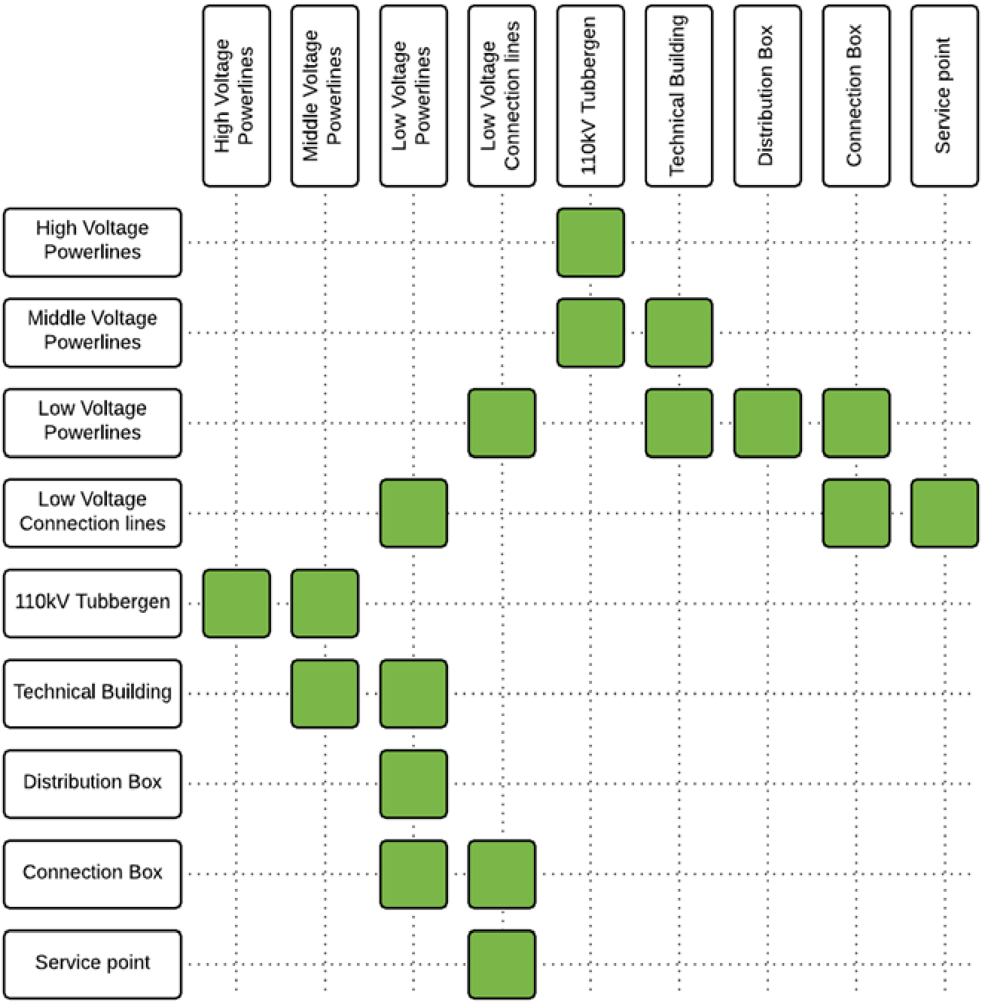

Figure 5.6 Interconnectivity between the various datasets of Enexis

5.4 Characteristics of the case area

According to Statistics Netherlands the average electricity consumption in the case area is around 3,900kWh per household. The amount of household in the region is according to Statistics Netherlands 7,856. When these two numbers are multiplied a total electricity consumption of 30,638MWh is calculated for all the households within the case area (Statistics Netherlands, 2015d). As explained in section 3.2 – *Electricity consumption in the Netherlands*, 20% of the electricity is consumed by households. This means for the case area that the total energy consumption should be around 153,190 MWh. The data of Enexis only represents the electricity consumption of the households and therefore the total consumption of only the households have been used for further analysis.

According to the Statistics Netherlands 8,167 residential buildings are within the borders of the case area, the Enexis Open Asset dataset has 8,517 service connection points in the case area. Among these are also the connection points of commercial and industrial buildings. According to the KlimaatMonitor, in the municipality of Tubbergen, which is roughly the same size as the case area, around 3,300GWh of renewable electricity is produced in 2015 (2015). This is 2.2% of the total electricity consumption in the case area.

5.5 Transition requirements

Based upon the various transition scenarios that have been discussed in chapter 4 – *Theoretical framework*, a transition scenario has been designed for the case area. The energy transition scenarios that have been reviewed had all a very economic approach in which the costs and time frame were leading for the transition. The impact on the electricity grid was less work out in the reports. Since this research focusses on a data assessment the energy transition scenario designed for the case area focusses more on the implications on the electricity network and not on the costs or the time aspect of the transition.

Due to the lack of large waterbodies or rivers hydro power is not a very viable source for electricity production in the case area. However, due to the low population density in the case area of around 140 inhabitants per square kilometer the implementation of windmills might be suitable for the case area. In addition to that, the relative high production windmills have and the low energy consumption in the area makes it possible that only a few wind turbines will be enough to supply the demand. In addition to that in the area are already three biomass converters that convert biomass into gas. In one of these facilities the gas is used to produce electricity. In this research these converters are regarded as extra energy sources to cover dips in the electricity production of solar and wind.

Criteria for the energy transition scenario

- *50% electricity production from solar roofs*
- *50% electricity production from wind turbines*

Variables that will be ignored due to complexity are:

- *Day and night differences in electricity consumption*
- *Seasonal changes in electricity consumption*
- *Future changes in electricity consumption*
- *Costs of the transition scenario*
- *Time frame for the implementation of the scenario.*

6

RESULTS

6. Results

In this chapter the results of the thesis are presented. In chapter 5 – Case study some results about the Open Asset data assessment were already presented. This chapter further reflects on these, starting with the creation of the service areas in the case area, followed by a comparison between the conceptual electricity network presented in chapter 3 – Contextual Framework and a tailor-made electricity concept. This chapter furthermore shows the results of the proposed energy transition from chapter 5 – Case study.

6.1 Service areas

The first part of the data assessment was to identify and create service areas from the technical buildings. Since these buildings cascade the 10.000 voltage to a 400 voltage which is suitable for residential connections, service areas for these buildings can be created. The intermediate distribution and connection boxes have transformed into connections between the low voltage cables (see paragraph 2.3.2 – *Transition scenario workout*).

Figure 6.1 shows a zoomed in map of the town Tubbergen within the case area. The yellow triangles represent the technical buildings that cascade the voltage onto the low voltage network. The different colors indicate the different service areas that were calculated without using the overlap function, because in a normal situation electricity is provided by the nearest source.

Figure 6.1 Map with the service area lines for the technical buildings.

Figure 6.2 shows the polygons that ArcMap creates using the network analyst – service areas tool. Enclosed lines within network become filled with the color of the service area, while single cables get a small buffer. However, as can be seen in the white circle this causes weird shapes that sometime overlap each other while this function was disabled in the tool. Therefore a different procedure has been followed to identify the service areas.

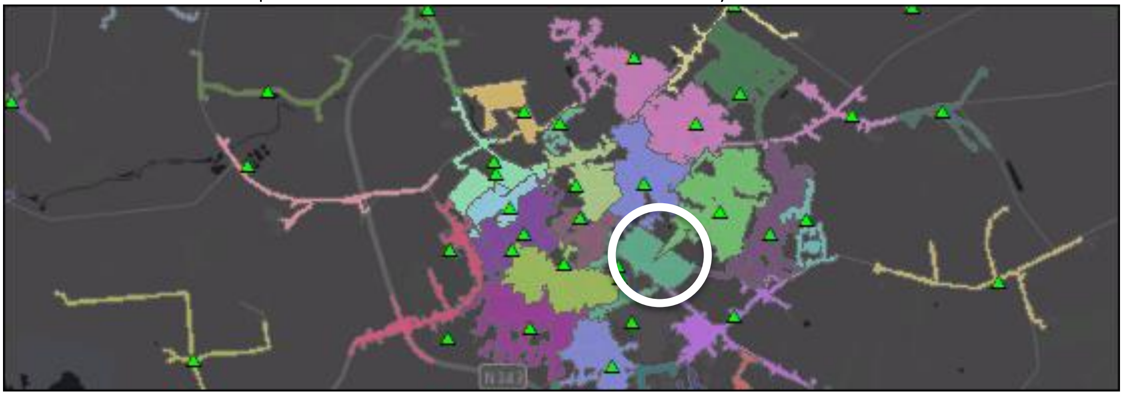

Figure 6.2 Polygons generated by the service area tool, in the white circle a strange overlap

Figure 6.3 shows the same service area lines but includes all service connections in the case area. The service connections are represented as the small orange points. These have been joined with the service area data by assigning the facilityID of the nearest technical building to every service connection point.

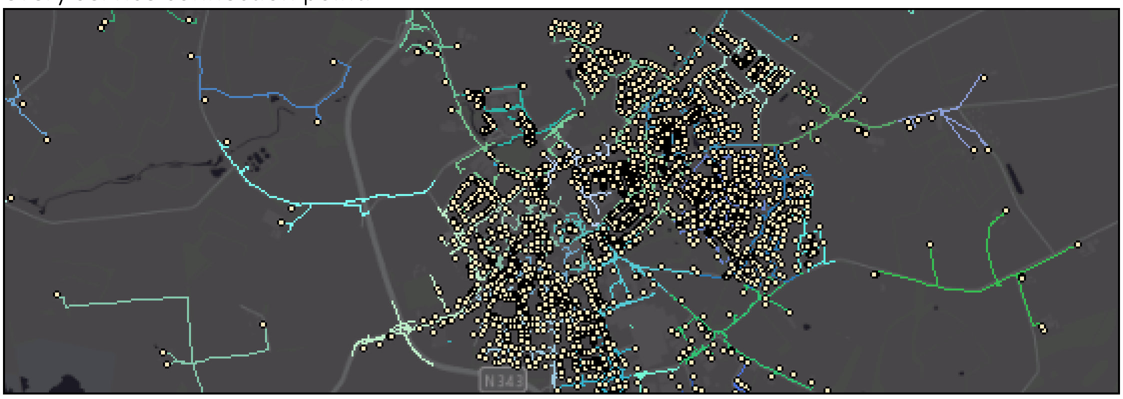

Figure 6.3 Service area lines together with service connection points for the identification of facilityIDs

With these facilityID connected to the service connection points Thiessen polygons were created using the facilityIDs to identify the individual service areas. These Thiessen polygons are presented in figure 6.4. The colors used to fill the polygons represent the estimated area size of the service area.

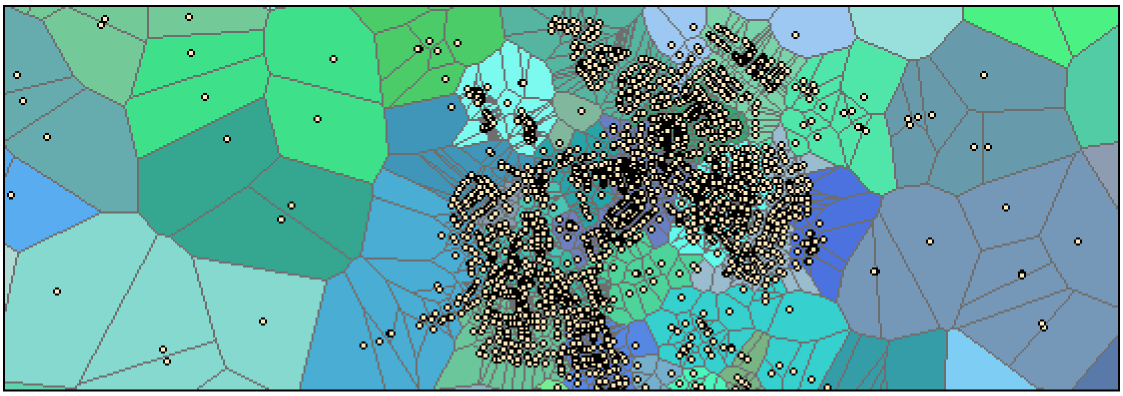

Figure 6.4 Thiessen polygons visualized in the matching facilityID colors.

In Figure 6.5 the lines between identical facilityID polygons have been dissolved and the service connection points have been removed from the visualization to show the service areas in the case area. Note that the service areas were calculated with the function to overlap each other disabled. In this map the technical buildings are again represented to indicate where the electricity is coming from for each individual service area

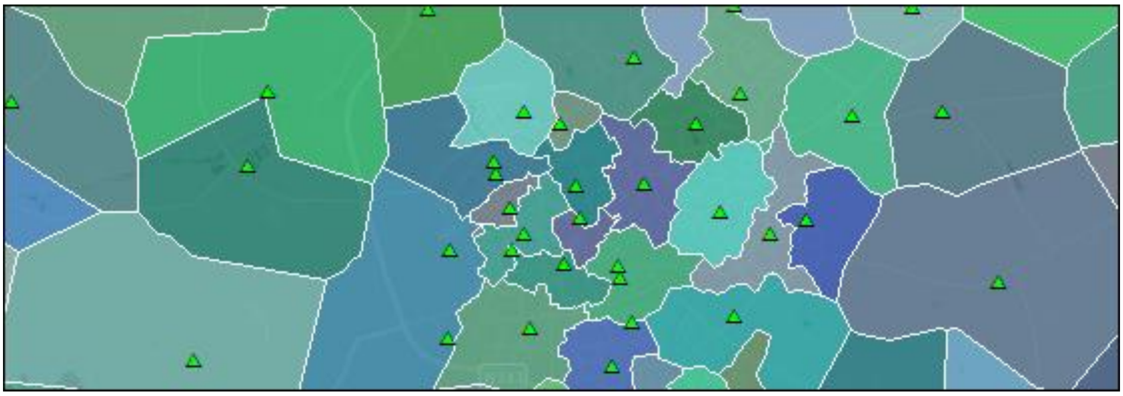

Figure 6.5 Non-overlapping service areas generated from the dissolved Thiessen polygons

With this function of overlap enabled, the service areas change mostly in the denser populated areas. The larger service areas in the outskirts that only contained a few service connection points remained roughly unchanged. However especially the town of Tubbergen was merged into a larger polygon representing the service area. This means that it is impossible to monitor exactly with this dataset which house get the power from which technical building due to the high connectivity. This is in contrary to the electricity grid concept presented in section 4.2 – *Electricity Grid Concept*. Therefore a new concept has been created that used the information gathered from the Open Asset dataset. This new concept is presented in section 6.2 – *Network Conceptualization.*

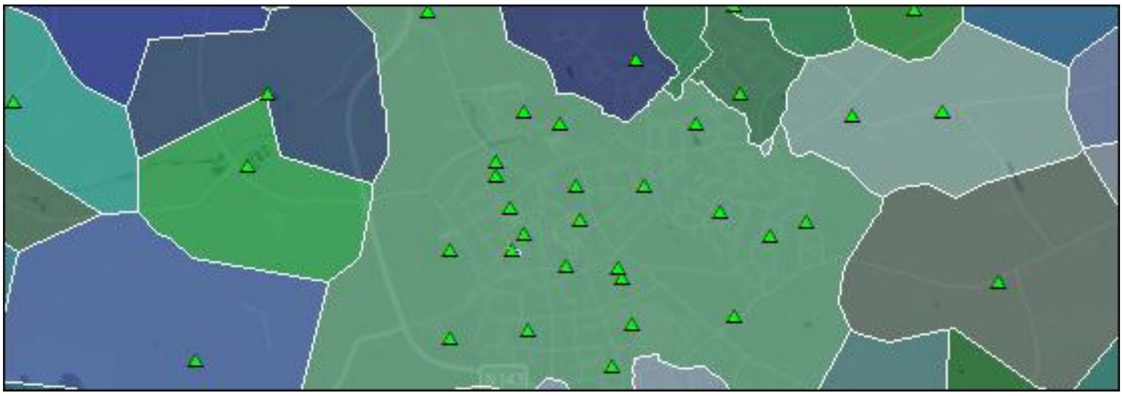

Figure 6.6 Service areas when connected networks are dissolved into one service area

6.2 Network conceptualization

In section 4.2 – *Electricity Grid Concept* a conceptualization of the electricity network was created using various models presented in academic literature, blogs and energy websites. With the information gathered in chapter 5 – *Case study*, and section 6.1 – *Service Areas*, a new visualization of this concept has been constructed.

Figure 6.7 depicts the new concept of the electricity network. It becomes clear that the actual network that has been assessed is much more complex than expected according to the literature. In contrary to what was expected, the connections do not always appear at the end of the low voltage network. In addition to that, distribution transformers are not always in the network and connections can be directly attached to substations as well.

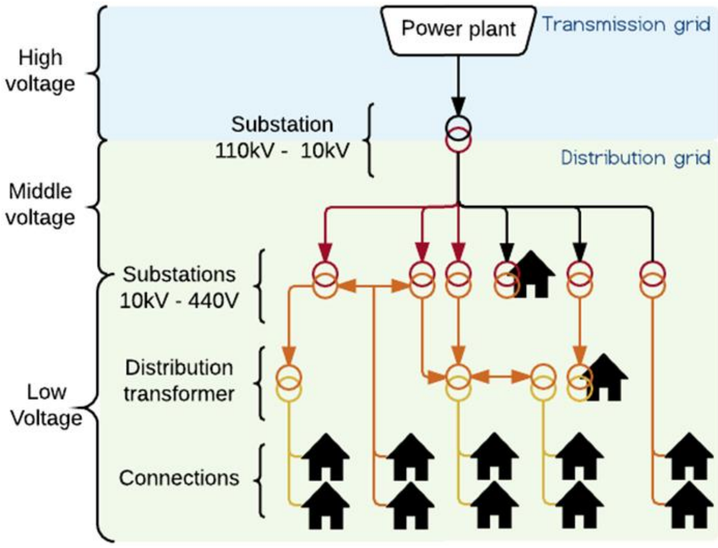

Figure 6.7 Conceptual electricity network according to the Open Asset data

The fact that is impossible to trace the electricity consumption of a connection back to a single substation makes it harder to identify how the electricity is actually divided and consumed, or produced and fed back to the system. This also clarifies the overlapping service areas of the substations in the case area, since more than one substation can supply the power in a certain region. This does not mean that the network is not usable for modelling energy transitiontions, but means that identifying technical buildings, or meter boxes at risk (due to overpowering) is impossible.

6.3 Suitability analysis for solar panels on rooftops

As proposed in chapter 5 – *Case study*, 50% of the energy production in the transition scenario will be covered by the implantation of solar panels on rooftops in the case area. In order to identify these locations, a requirements table has been constructed in paragraph 6.3.1 – *Requirements for solar roofs*, this table contains all data information for the analysis. The analyses that are done with this data are presented in paragraph 6.3.2 – *Analyses procedure and outcome*. Finally sensitivity analyses have been done which are presented in paragraph 6.3.3 - *Sensitivity*.

6.3.1 Requirements for solar panels on rooftops

For the determination of suitable rooftops for solar panels a requirements table has been built (see table 6.1). This table contains all necessary data sources and preparations steps and is used to identify all criteria and list them. In chapter 4 – *Theoretical Framework* some of the defined requirements were explained. In that same chapter the motivation for the aspect and slope values are presented as well.

For the placement of solar panels on rooftops the slope and aspect are important to maximize the efficiency of solar irradiation. Apart from that, for this analysis it is also important that all potential buildings have a service connection. This means that the building has an electricity box in the house, since otherwise it is impossible to trace back where the electricity surplus produced by the solar panel would go to. The data of service connections is in the Open Asset dataset of Enexis. Finally the areal efficiency has been calculated to eliminate large but useless areas (more information about this is further down below).

Table 6.1 Requirements for photovoltaic cells on rooftops

#	Requirement	Defined	Spatial data	Attribute data	Dataset	Preparation
1	rooftop		rooftop		BAG	
2	15m2 or more			area	BAG	calculate
3	within case area		case area		case area	
4	with connection			service connection	service points	
5	right slope	25°-40°	slope		AHN	surface slope
6	right aspect	140°-220°	aspect		AHN	surface aspect
7	areal efficiency	>0.8				calculate

The largest buffer that is requested in both requirements tables (table 6.1 and 6.2) is 500meter (apart from the airport buffer, but no airport was near enough to the case area to effect the outcome). Therefore the entire research area was determined to be the case area including a buffer of 500 meter to make sure that all phenomena that are right across the border of the case area were taken into account as well.

6.3.2 Analysis procedure and outcome

Due to the high detail level of the analyses and maps, only a zoomed-in version of the outcomes will be shown to give a better idea of what the results are.

In order to meet requirement #1 from the requirements table all buildings have been imported from the BAG dataset. From these buildings a selection has been made with 'select from location' with all buildings in which a service connection was found. This resulted in the figure 6.8. The buildings that meet these requirements are visualized as light grey polygons with white outlines.

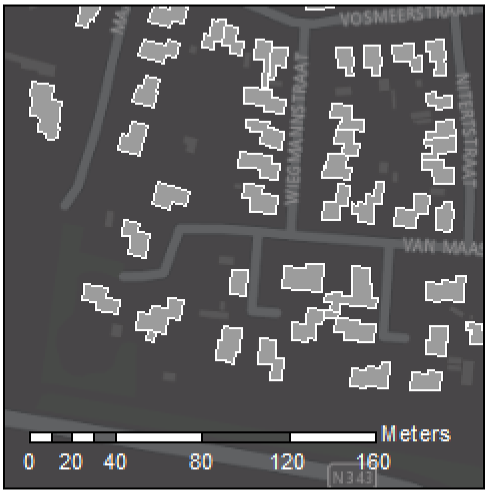

Figure 6.8 Remaining BAG outlines that have a service connection

Slope

As defined in the requirements table a slope of 20° to 45° is preferred for optimizing the efficiency of the solar panels. The slope for the research area has been calculated by using the AHN2 (50cm raster) shape file and the tool Surface Slope. This resulted in the map shown in figure 6.9. A more zoomed-in version is visible in Figure 6.10 and clearly the difference in slope levels can be distinguished. Figure 6.11 depicts the same layer but with the defined spatial requirements used to visualize the suitable areas in terms of surface slope.

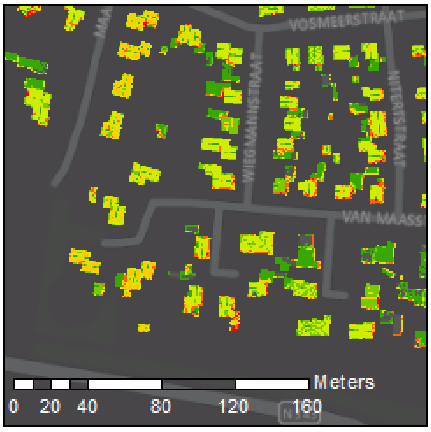

Figure 6.9 Surface slope

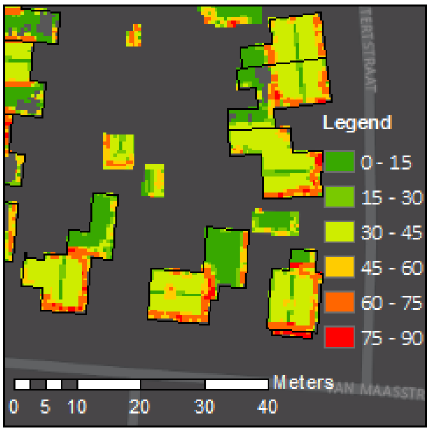

Figure 6.10 Zoomed-in surface slope

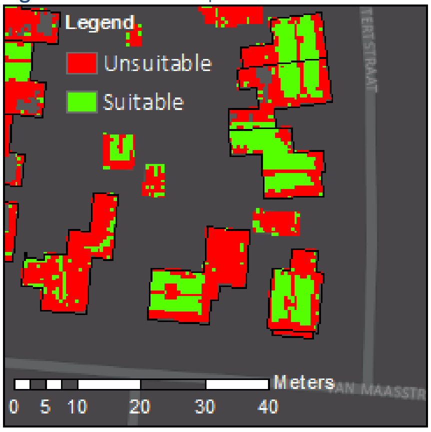

Figure 6.11 Suitable slope

Aspect

As defined in the requirements table an aspect of 140° to 220° is preferred for optimizing the efficiency of the solar panels. The aspect for the research area has been calculated by using the AHN2 (50cm raster) shape file and the tool Surface Aspect. This resulted in the map shown in figure 6.12. A more zoomed-in version is visible in Figure 6.13 and clearly the difference in aspects can be distinguished. Figure 6.14 depicts the same layer but with the defined spatial requirements used to visualize the suitable areas in terms of surface aspect.

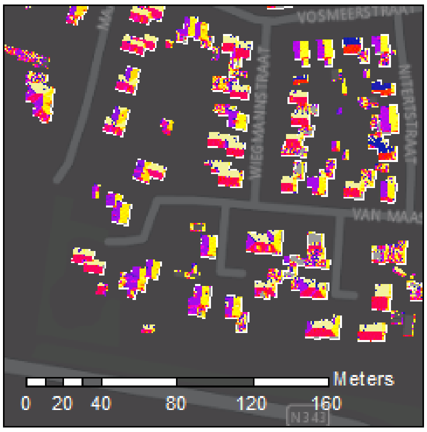

Figure 6.12 Surface aspect

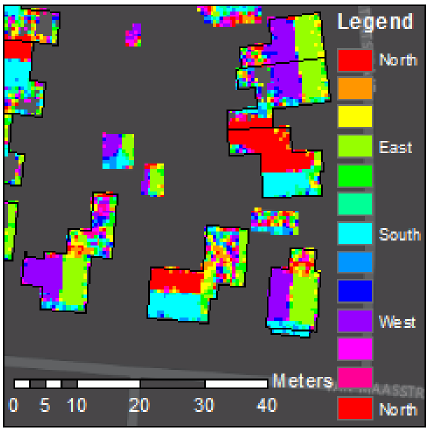

Figure 6.13 Zoomed-in surface aspect

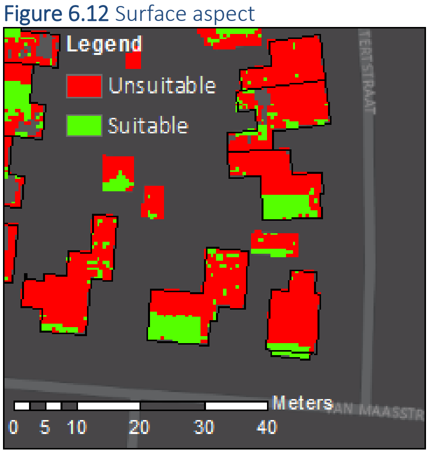

Figure 6.14 Suitable aspect

Results

These first results of the suitability analysis for solar roofs have been compared with the map presented by the Zonatlas. Zonatlas divides buildings into three different categories, less suitable, suitable and very suitable. Figure 6.15 is the map created keeping the intersecting suitable areas from the previous two steps. Figure 6.16 is a map created by Zonatlas. When comparing the two similarities can be found. Most buildings in figure 6.9 that have relatively large areas of suitability seem to correspond with the green buildings in the Zonatlas map. The red buildings in the Zonatlas map have not been taken into account in the suitability analysis due to the lack of a service connection (see requirement no.4 in the requirements table).

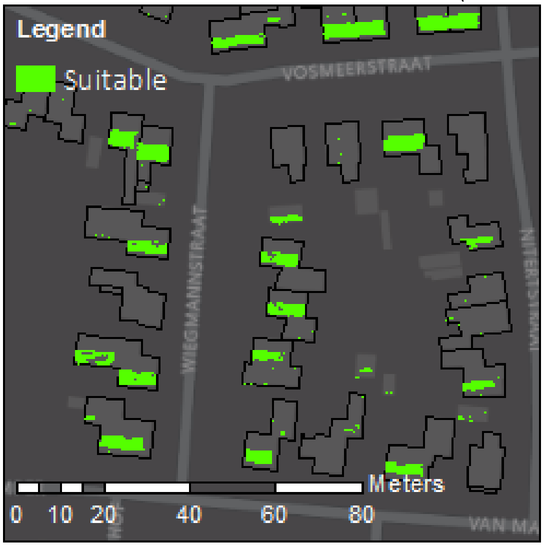

Figure 6.15 Suitability map for solar panels

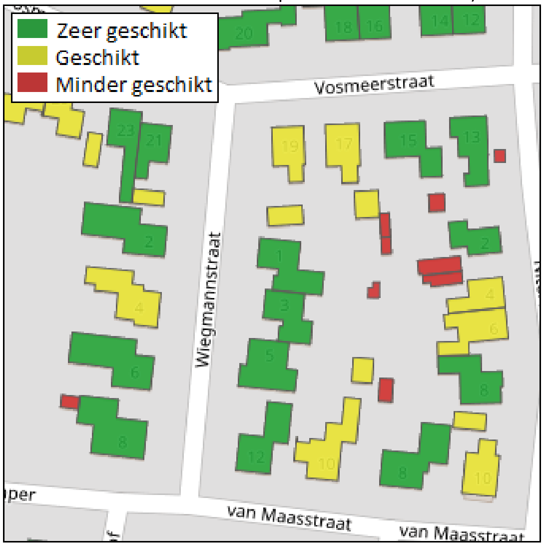

Figure 6.16 Suitability according to Zonatlas

Areal efficiency

Some possible rooftops had irregular shapes or were very 'spotted', making the area count high in terms of total area size, but being not very useful for the construction of solar roofs since it would be hard to cover all the small parts. This has been visualized in figures 6.17 and 6.18. Figure 6.17 shows a rooftop with a low areal efficiency of 0.45. It has the same area as figure but has an areal efficiency that is four times as high. Therefore the areal efficiency was calculated per rooftop. The lowest score in the dataset was 0.125, the highest 2.9.

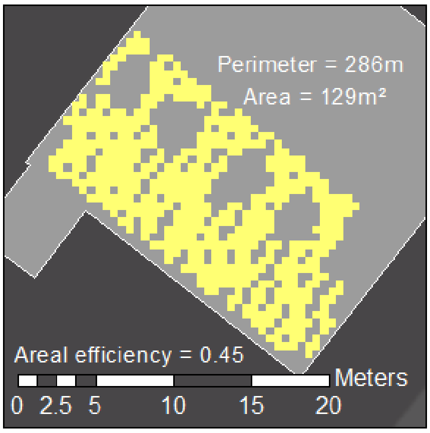

Figure 6.17 A rooftop with a low areal efficiency

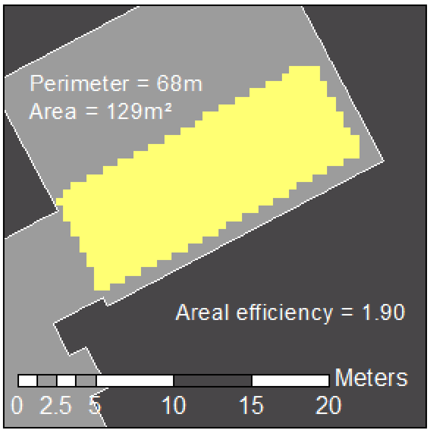

Figure 6.18 A rooftop with a high areal efficiency

This areal efficiency is calculated with the formula shown in Figure 6.19. Figure 6.18 shows a much higher efficiency than figure 6.17. The left map shows a rooftop with a high total area but also a high perimeter. The efficiency ratio of that roof

$$\frac{Area}{Perimeter} = areal\ efficiency$$

Figure 6.19 The areal efficiency

resulted in 0.45 and was regarded as insufficient.
Since the data was derived from the AHN, a raster dataset, the output was forced to be shaped like small raster tiles as well. Therefore, the 'best' possible area should be a perfect square since that gives the highest areal efficiency in relation to the area size. Figure 6.20 visualized the region that is regarded as suitable for the solar rooftops. In this figure a division has been made between; higher than 0.8 and lower than 0.8, paragraph 6.2.3 – *Sensitivity* explains why.

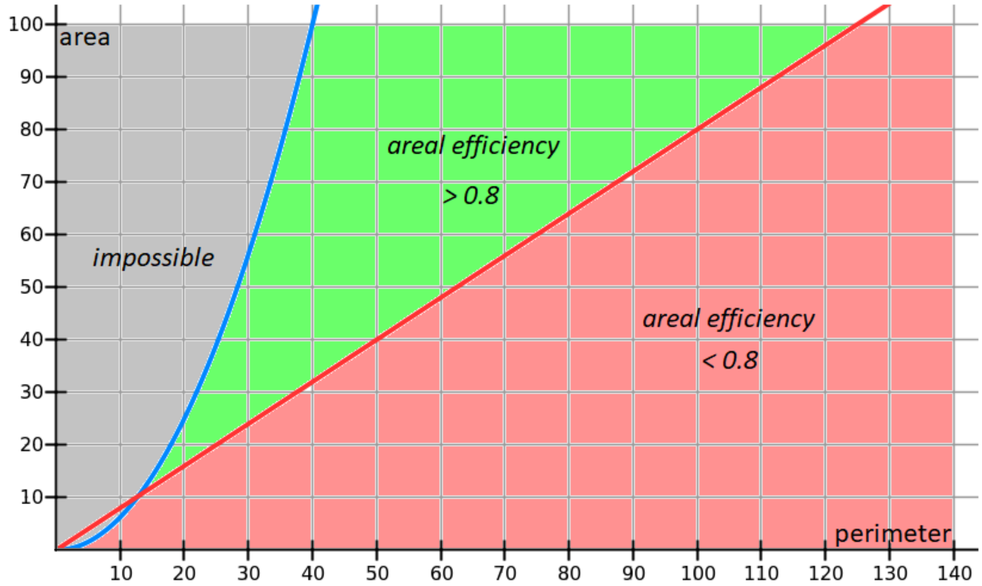

Figure 6.20 Visualization of the areal efficiency formula

6.3.3 Sensitivity

The criteria for both the size of the suitable roofs as well as the efficiency ratio are not defined by literature. However, a higher score on any of the two values is always preferred. In order to make a balanced decision on which roof top size and which area efficiency are used for further analysis, a sensitivity analysis has been done. This analysis is visible in the tables 6.2, 6.3, 6.4 and 6.5. In total 24 different combinations have been selected and reviewed.

Table 6.2 Amount rooftops with various variables

	EF ≥ 1	EF ≥ 0.9	EF ≥ 0.8	EF ≥ 0.7
≥ 3 m^2	159	286	465	687
≥ 5 m^2	159	286	465	687
≥ 10 m^2	159	286	465	687
≥ 15 m^2	159	286	464	649
≥ 20 m^2	156	257	374	481
≥ 25 m^2	129	184	246	295
≥ 30 m^2	104	139	176	208

Table 6.3 Total area in m² with various variables

	EF ≥ 1	EF ≥ 0.9	EF ≥ 0.8	EF ≥ 0.7
≥ 3 m^2	8,415	12,020	16,842	21,837
≥ 5 m^2	8,415	12,020	16,842	21,837
≥ 10 m^2	8,415	12,020	16,842	21,837
≥ 15 m^2	8,415	12,020	16,827	21,320
≥ 20 m^2	8,356	11,483	15,204	18,362
≥ 25 m^2	7,741	9,840	12,343	14,215
≥ 30 m^2	7,066	8,618	10,440	11,855

Table 6.4 Potential electricity generation in MW

	EF ≥ 1	EF ≥ 0.9	EF ≥ 0.8	EF ≥ 0.7
≥ 3 m^2	8.306	11.864	16.623	21.553
≥ 5 m^2	8.306	11.864	16.623	21.553
≥ 10 m^2	8.306	11.864	16.623	21.553
≥ 15 m^2	8.306	11.864	16.608	21.043
≥ 20 m^2	8.247	11.334	15.006	18.123
≥ 25 m^2	7.640	9.712	12.183	14.020
≥ 30 m^2	6.974	8.506	10.304	11.701

Table 6.5 Percentage of required electricity

	EF ≥ 1	EF ≥ 0.9	EF ≥ 0.8	EF ≥ 0.7
≥ 3 m^2	27%	39%	54%	70%
≥ 5 m^2	27%	39%	54%	70%
≥ 10 m^2	27%	39%	54%	70%
≥ 15 m^2	27%	39%	54%	69%
≥ 20 m^2	27%	37%	49%	59%
≥ 25 m^2	25%	32%	40%	46%
≥ 30 m^2	23%	28%	34%	38%

As the sensitivity analysis showed, with an EF of more than 0.9 it is impossible to reach 50% of electricity production (see Table 6.5). In addition to that also a roof top area size of more than 25m² leads to this issue of lack of coverage. The two options, EF≥0.9 and ≥15m2, and EF≥0.7 and ≥20m2 both result in a higher than 50% coverage of electricity production. However, the first of these two requires only 464 rooftops covered with solar panels, while the latter requires 481. It is expected that placing a smaller amount of solar roofs will be cheaper due to the installation costs. The chosen criteria for further analysis are shown in green in the tables above. Figure 6.21 below shows the remaining solar roofs in a part of Tubbergen. The white box on the left indicates the area that was shown in figure 6.15.

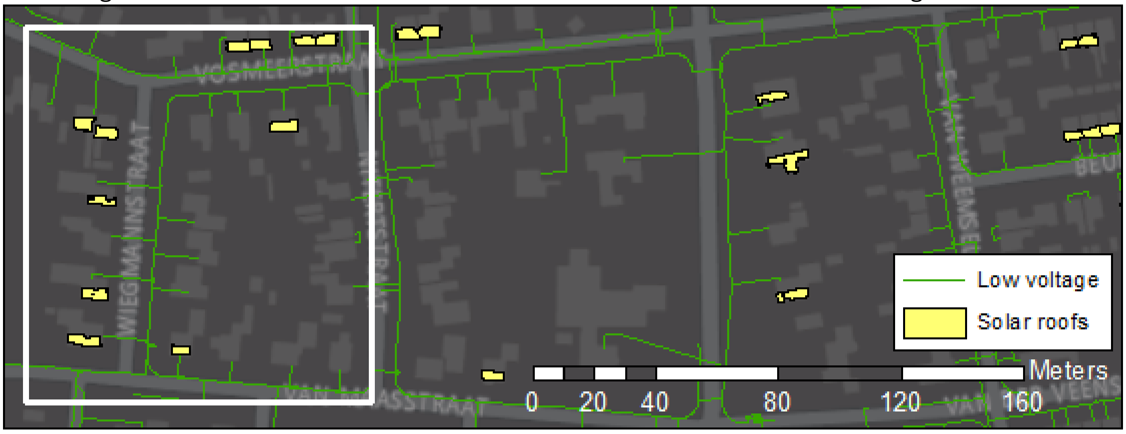

Figure 6.21 Remaining solar roofs in the case area

6.4 Suitability for windmills

As proposed in chapter 5 – *Case study*, a part 50% of the energy production in the transition scenario will be covered by the implantation of wind turbines in the case area. In order to identify a requirements table has been constructed in paragraph 6.4.1 – *Requirements for windmill locations*, this table contains all data information for the analysis. The analyses that are done with this data are presented in paragraph 6.4.2 – *Analysis procedure and outcome*. Finally some sensitivity analyses have been done which are presented in paragraph 6.4.3 - *Sensitivity*.

6.4.1 Requirements for windmill locations

For the determination of locations of wind energy farming a requirements table has been made to identify restricted and favorable environment. In this requirement table all datasets and their preparation are presented. It serves as an overview of all criteria that have been put together for the suitability analysis. The requirements table for determining the windmill locations is Table 6.6. Like with the suitability for solar roofs, for the suitability analysis an area 500meter bigger than the case area has been used in order to make sure that phenomenon that were right across the case area's border were taken in to account as well.

Table 6.6 Requirements for wind energy farming

#	Requirement	Defined	Spatial data	Attribute data	Dataset	Preparation
1	Land parcel		parcel		parcels	
2	Large enough	>10m^2		area	parcels	calculate
3	within case area		case area		case area	
4	away from buildings	>500m	buildings		BGT	buffer
5	away from roads	>10m	roads		BGT	buffer
6	away from road support	>10m	road support		BGT	buffer
7	away from water	>10m	water		BGT	buffer
8	away from water support	>10m	water support		BGT	buffer
9	away from railways	>10m		spoorbaan	BGT	buffer
10	away from airports	>1km		baan voor vliegverkeer	BGT	buffer
11	not within natura2000		natura2000		natura2000	

The requirements that have been selected for the windmill suitability can be divided into three different groups. The first group is called the 'no go' area. This encompasses all area's in which the construction of windmills is not wanted. These are in this research; roads, water, railroads, airfields, protected nature and buildings. For this research it was assumed that none of these would be destroyed or replaced in order to construct a windmill. Buffers have been added to these layers that indicate the areas around the spatial phenomena that are regarded as unsuitable for constructing wind mills. The second group is called the 'go' area. In this group are the layers that are regarded as suitable for constructing. For the suitability of windmills the 'go' area is the case area, since one of the requirements of the transition scenario is to make the area self-sufficient in power supply. This means that all energy generating facilities should be in the region. The third group of criteria that has been taken into account for the suitability is the characteristics of the data that can be found in the attribute table. For this research it was determined that the minimum area to take into account for the placement of a windmill was 10m2. In reality this might be too small for placing an actual windmill, but it is primarily meant to eliminate even smaller areas.

6.4.2 Analysis procedure and outcome

Figure 6.22 shows both the case area and the study area (darker green). The buffer of 500 meter around the case area is visible. This buffer makes sure that all phenomena that are across the border of the case area are taken into account as well, since these might influence the suitability of the edges of the case area. Especially for criteria four, 500 meter away from buildings, this is an important measure.

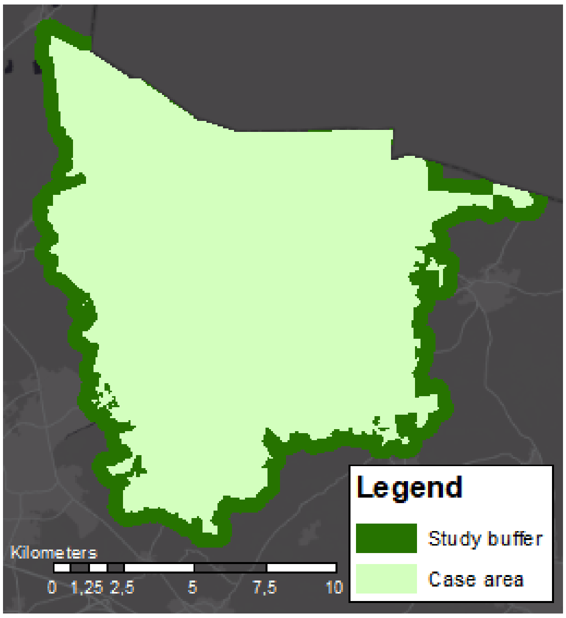

Figure 6.22 Case area and the study area

In Figure 6.23 the restricted infrastructural areas are colored red. Since most of the infrastructure maps consist of line data, buffers have been created to identify the unsuitable areas around the roads. All these individual maps are then combined into the map visible in figure 6.23. The more sparsely populated areas can be identified by the lower amount of red lines. In the case area or around it were no railroads or airports that influenced the suitability of the area.

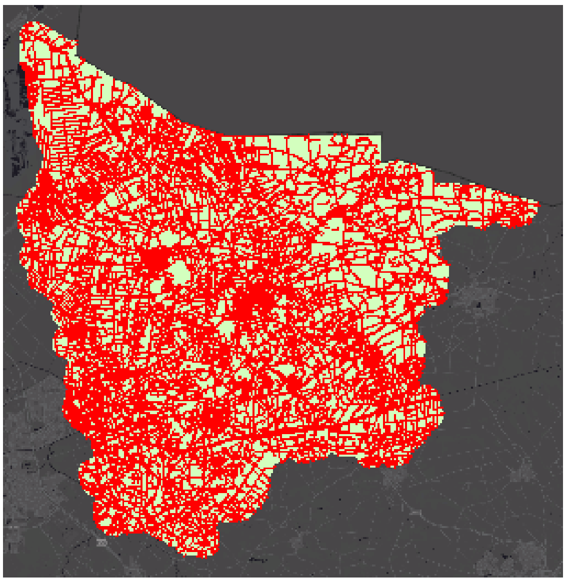
Figure 6.23 Restricted infrastructure in the study area

Apart from the infrastructural restrictions, there are also protected nature areas. These nature reserves are listed in the Natura2000. The clipped version on study area size is visible in figure 6.24. In the study area are two large nature reserves, these are the Engbertsdijksvennen in the north-west and the Springendal and Dal van de Mosbeek in the north-east. The Engbertsdijksvennen are almost completely in the 500 meter study buffer and therefore have little to no impact on the suitability analysis.

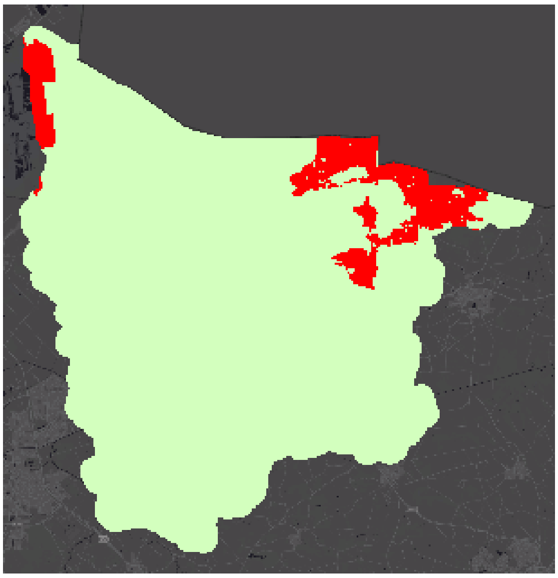

Figure 6.24 Natura2000 areas in the study area

Due to the strong NIMBY-effect on the construction of windmills (see section 4.7 – *Windmills*), a buffer of 500 meter has been created around all buildings that are, accordingly to the BAG, in the study area. Not all of these buildings might be inhabited since many of them function as stables, barns or sheds. As can be seen in figure 6.25, this buffer eliminates most of the study area, leaving only a few spots that remain suitable.

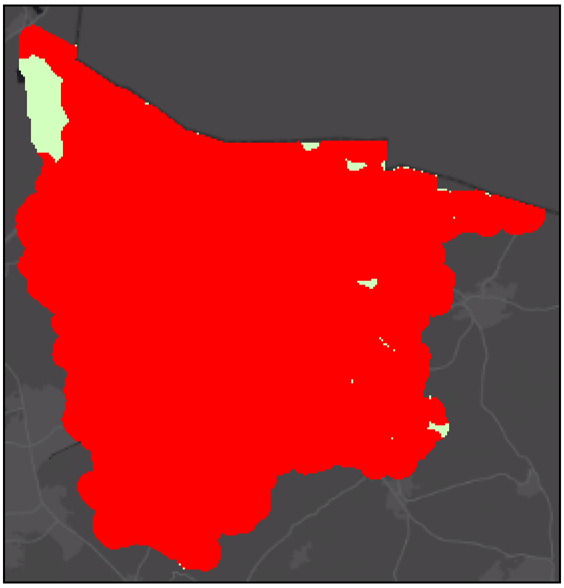

Figure 6.25 Areas too close to buildings

All restricted areas shown in the previous maps have then been merged into one layer containing all restricted areas, with the erase tool the remaining suitable spots were extracted from the case area. After that all areas that were smaller than 10m2 were removed. The remaining areas are shown in dark green in Figure 6.26 below. In total 9 different areas were identified as suitable for the placement of at least one wind turbine regarding the predefined requirements. Since wind turbines need to be connected to the middle voltage network, this network has been depicted in figure 6.26 as well.

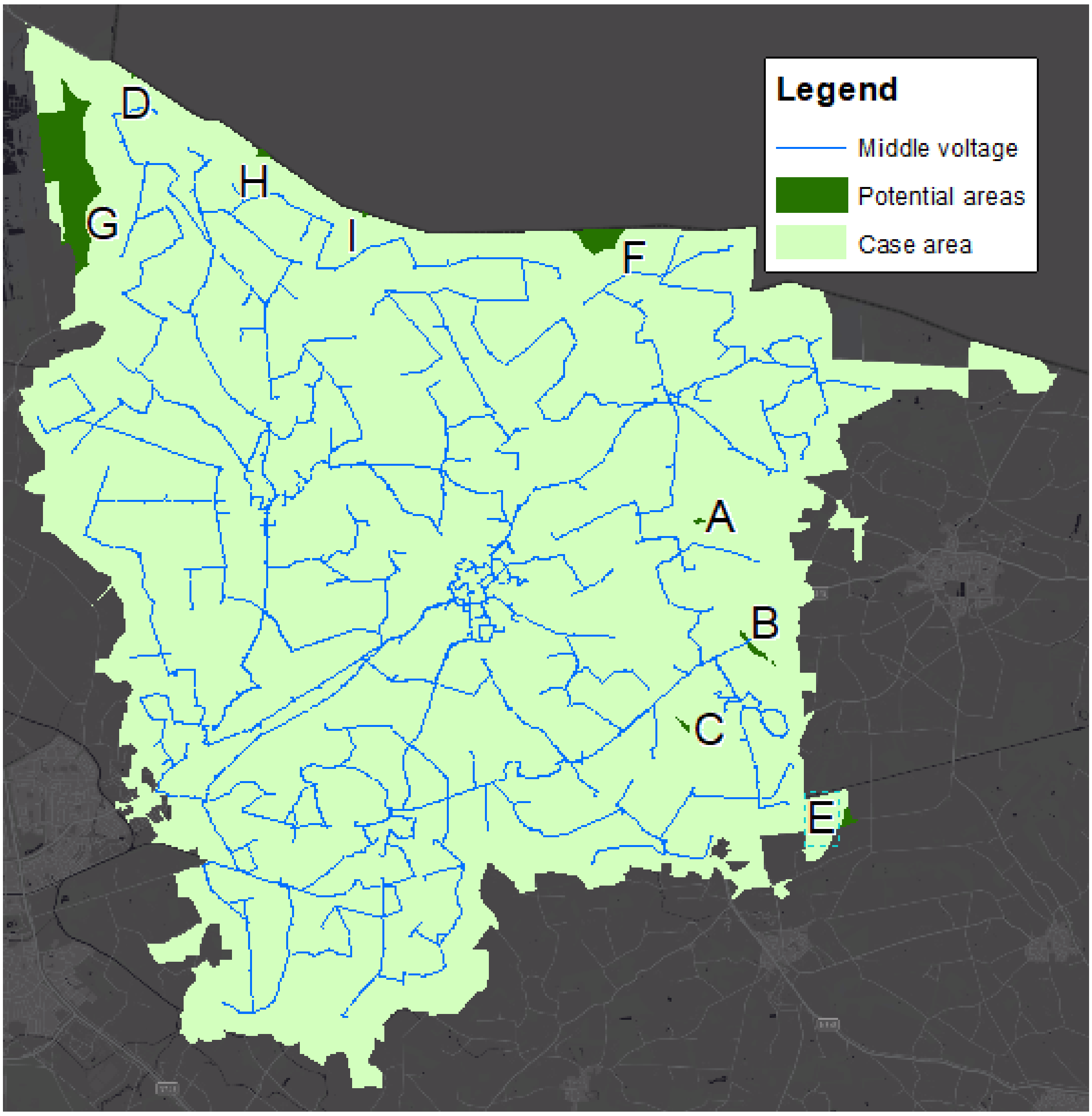

Figure 6.26 The nine possible locations for wind turbines

Figure 6.27 shows all nine individual areas. Important to note is the various scales the maps have due to the variety in area sizes. Some areas consist of multiple parts due to the presence of waterways or roads. Area D is the smallest of the nine with 1.211m², the largest is area G which is over 1.4 million square meters. The location of these 9 suitable spots is primarily along the borders of the case area.

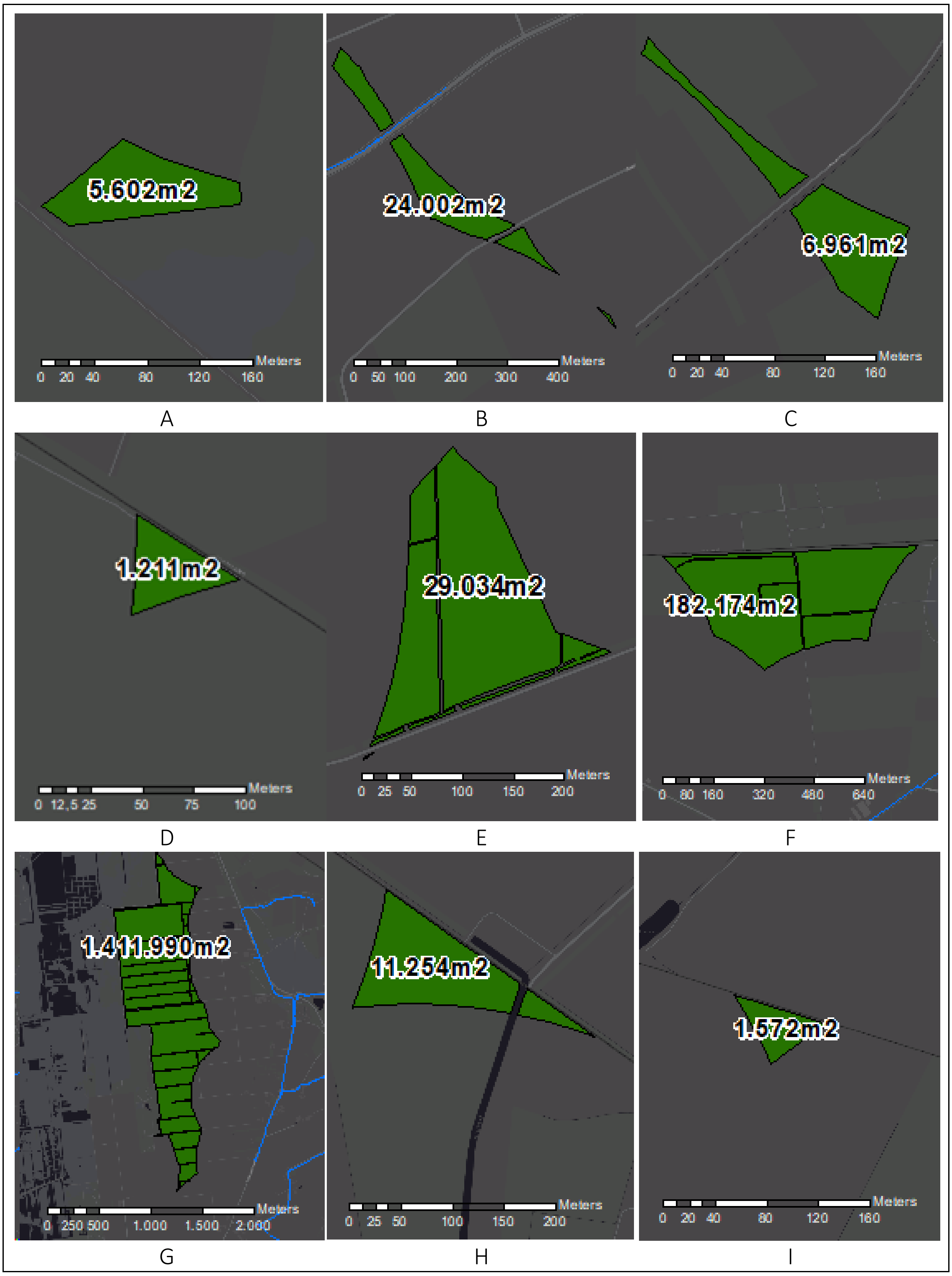

Figure 6.27 The nine individual suitable areas

In table 6.7 the characteristics of each individual suitable area are further identified. The table shows the distance to the nearest connection with the middle voltage network. As explained in section 4.7 – *Windmills*, wind turbines need to be connected to the middle voltage to function. The last three columns of table 6.7 give an indication of the amount of windmills that can be placed using the three different distance limits given in section 4.7 – *Windmills.* As proposed in section 5.6 – *Transition requirements,* at least 50% of the electricity in the area should be generated by wind mills. This means that two large windmills with a yearly productivity of 75GWh should be enough to gather at least 50% of electricity. According to the suitability analysis it is possible to place at least two windmills within the case area.

Table 6.7 Characteristics of the nine potential wind turbine areas

Letter	Parts	Case area-locked	Bordering Germany	Bordering Municipality	Size in m2	Distant to nearest Mv	Longest line	250m	640m	1300m
A	1	X			5,602	338m	152m	1	1	1
B	4	X			24,002	9m	766m	4	2	1
C	2	X			3,931	347m	287m	2	1	1
D	1		X		1,211	539m	59m	1	1	1
E	8			X	29,034	949m	316m	3	1	1
F	4		X		182,174	476m	812m	7	2	1
G	10			X	1,411,990	440m	3,230m	10+	9	3
H	3		X		11,254	612m	248m	1	1	1
I	1		X		1,572	526m	76m	1	1	1

6.4.3 Sensitivity

A small sensitivity analysis has been done with the data gathered in the suitability analysis of the wind mills. Since most of the variables used in the requirements table deal with buffers, a relatively high sensitivity is noticed in the outcome of the analysis. The 500meter buffer around all buildings has a relatively large impact on the suitable areas. In addition to that in this case the entire buffer zone has been identified as a no-go zone. Using multiple buffer rings or a gradual buffer for the identification of suitable areas would have changed the outcome. However, these modifications in the analysis procedure would change the sizes of the suitable areas or some would disappear, no new or more suitable areas would pop up when these options are used.

7

CONCLUSION

7. Conclusion

In this chapter the conclusions and discussion of the thesis are presented. This chapter reflects on the results from chapter 6, taking the goals and research questions from chapter 1 – Introduction in mind. The chapter starts with the conclusions in the order of the objectives and research questions. After that the internal discussion takes place, in this section the outcome of the thesis and the quality of the results will be discussed. In the external discussion the results and conclusions will be discussed regarding findings in the academic world. The third part of this chapter contains the recommendations for further research.

7.1 Conclusions

The conclusions below are written in the same order as the objectives and research questions were written in chapter 1 – *Introduction*.

7.1.1 Objective 1

The first objective of this research was to construct a contextual and theoretical framework regarding energy production, consumption and transitions. The realization of these two objectives was respectively presented in chapter 2 – *Contextual Framework* and chapter 3 – *Theoretical framework*. The objective resulted in the following conclusions:

In the Netherlands around 87% of the electricity consumption is produced in the country itself. Around 67% of this generated electricity comes from burning fossil fuels, 12% of the production comes from renewable sources. A small amount of electricity is generated by nuclear power or other sources. The total capacity of the production facilities is around 31.5GW. 20.1GW or 64% of this potential production is centrally organized. While the other 11.4GW or 36% comes from decentral electricity production, this share is growing each year. The average electricity consumption per household has been stable for decades due to electric appliances becoming more energy efficient. The shortage of electricity is covered by importing electricity from neighboring countries. Whenever a production surplus occurs, this extra electricity is used in Norway to pump water back into a lake and save it for later.

According to the literature the energy network can be conceptualized using three different network types. The mesh network is present in the high and middle voltage network. In these layers the nodes are connected with multiple other nodes and the network looks like a spider web. The low voltage network can be conceptualized in two different network types. The distribution network has the shape of a (span) tree. In this network a few nodes (often distribution boxes) redistribute the electricity. The low voltage connection network is shaped in the bus network type where the actual service points or connected.

Energy transitions are not something new, many have occurred before this one. The current energy transition is characterized by its shift from fossil fuels towards renewable sources such as wind, water and solar energy. Where other transitions where technology driven, this transition is pushed by the public and pressure groups that demand a cleaner environment. Some countries are further than others in this energy transition. The Nordic countries for example all excel in the use of renewable sources primarily due to the high potential for water energy in the mountains.

When looking at the design of energy transitions in other regions it is remarkable that most reports have a very theoretic approach. They often come with percentages of electricity production with matching time and costs perspectives. However, only little to none attention is payed to the spatial implications of an energy transition. In particular the electricity network is neglected in these studies. Most studies do talk about the smart grid and how it would influence the energy consumption, storage and therefore production, but a concrete workout of the implications on the actual physical electricity grid is often missing.

7.1.2 Objective 2

The second objective of this research was to select a suitable case area for the data quality assessment. This objective was mainly presented in chapter 5 – *Case study*. The objective resulted in the following conclusions:

The requirements that were selected for the site selection were; a relative small area, located in the Netherlands that can easily be isolated from the rest of the network. This is already an optimization since the complexity of the network will be mitigated. A case study area was found in the east of the Netherlands. This case area in the east in the Netherlands covers approximately the municipality of Tubbergen. The case area is shown in figure 7.1

Figure 7.1 The selected case area

7.1.3 Objective 3

The third objective of this research was to analyze and explore the quality of the open energy dataset, and the current state of the case area in general. This objective was mainly presented in chapter 5 – *Case study* and chapter 6 - *Results*. This objective found out that in the case area 3,300 MWh of electricity is produced, this is approximately 2% of the case area's electricity consumption. In addition to that the case area consists of 7,856 households and an estimated 21,142 inhabitants.

In addition to that service areas were generated. This step found out that the actual network provided in the Open Asset dataset is not as simplistic as expected from the electricity grid concept, which was a span tree, created in objective 1. The developed concept of the electricity network in the case study area differs from the concept based on models presented in literature, blogs and energy websites. Figure 7.2 and 7.3 show both conceptual models. Clearly the higher complexity can be identified in the model based on the Open Asset dataset from Enexis. This is already a part of the data assessment. The expected span tree structure visible in

Figure 7.2 was rarely found in the Open Asset dataset, the mesh network structure was much more present. In addition to that the expected consistent hierarchy in different levels of voltage networks and transformer houses was also not present in the actual data. This can be seen as the first phase of the assessment.

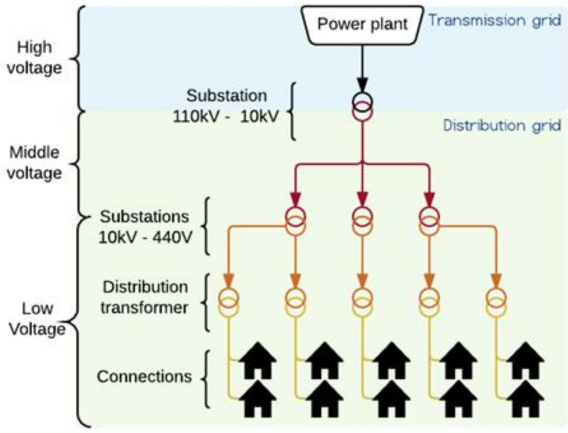

Figure 7.2 Electricity network based on literature

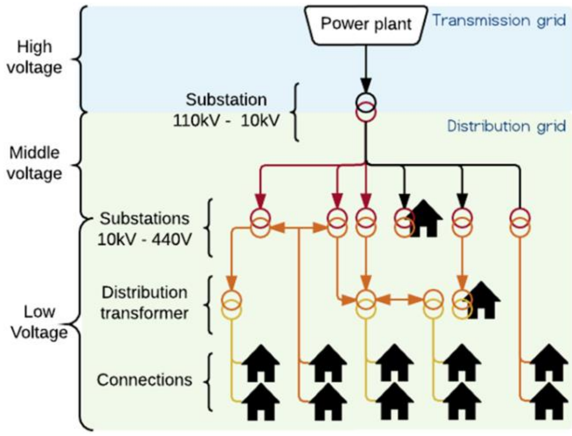

Figure 7.3 Electricity network based on data assesment

The transition scenario that has been designed for the data assessment consisted of a 50/50 division between solar energy and wind energy. Making use of hydro power, a common renewable energy source, was excluded due to the low potential in the case area. Within the case area are already three biomass converters present that could cover the local electricity request when the two other sources are not sufficient. Since the main goal of this research was to assess an open dataset, factors such as day/night, seasons, time-planning, costs and future prediction were ignored for the transition scenario design.

7.1.4 Objective 4

The second phase of the data assessment of data took place in two directions. The first was from the starting point of the electricity. This lead to the selection of the case area and the revised conceptual model of the electricity grid. The second direction was from the energy transition perspective. This direction looked at new possibilities of electricity production in the region. It identified rooftops that were suitable for generating electricity from the sun using the service connection points from the Open Asset data (see figure 6.12). For the calculation of wind energy the middle voltage network of the Open Asset data was used to identify the distance to the nearest middle voltage cable. Both analyses proved that reaching 50% production of electricity is possible in the case study area.

Through effective electricity storage peaks in the electricity demand can be covered. The use of a smart electricity saving grid could be the potential solution for this as described in *section 4.5 – Energy Storage Solutions*. Another method of dealing with peaks is the use of the three presented biomass converters that are already presented in the case area. The open asset dataset of Enexis encompasses the current EV charging poles that could be used for the smart energy storage grid.

In the second phase of data assessing, the energy transition scenario concepts were applied on the open data, to see to what extend this data was useful. This led to the following conclusions:

1. ***There is insufficient metadata to work effectively with the open dataset***

The dataset of Enexis is very large and comprehensive. The detail level of the cables is high and there is a lot of metadata attacked to the various files in the energy dataset. However, modelling a transition scenario on household level is impossible to do. Important metadata about the capacity of cables and technical buildings is missing. It is unknown in the data how much electricity the different distribution and transformer boxes can handle. In addition to that important information about the individual cables is needed to make statements about their potential.

2. ***Information about interconnectivity is lacking***

Most cables (polylines) stop a few decimeters before they reach the 'point' of the distribution/connection boxes or the technical buildings. Often they end where the polygon of the transformer has been drawn. This makes it uncertain how the cables are attached within the distribution/connection boxes and the technical buildings. In paragraph 2.3.2 – *Transition Scenario Workout* was described how this issue was tackled in order to calculate the service areas. This method however created interconnectivity that was not proven to exist in the first place.

3. ***The electricity grid has a high complexity***

Besides shortcomings in the dataset also the complexity of the grid made it hard to work out an energy transition scenario. The electricity grid was expected to be simpler than most concepts described. Due to this complexity it was impossible to identify points in the network that could be at risk in case of electricity production surplus.

7.2 Discussion

In the discussion the outcome of the research is critically reflected. This is done in two different ways. First the internal discussion in which the method and procedure of the research itself is discussed, in addition to that it reflects on the assumption made in the beginning of the research. In the second part of the discussion the research is reviewed in the context of the academic environment. Are the findings in this research in line with common trends and similar studies and on what levels was this study unique.

7.2.1 Internal discussion

When reflecting on the outcome of the research and the assumptions made some critical notes can be placed. First, the incompleteness of the network might have influenced the results. As stated in the assumptions, a part of the electricity network in the Open Asset dataset is missing (municipality of Almelo). This area is bordering the case area and the possibility exists that there are connections between the two areas. This creates some uncertainty regarding the service areas on the edges of the case area.

Secondly, many factors and variables that influence electricity consumption have been neglected in the analysis and have been identified as a constraint in the introduction. Among these are day and night differences, seasonal changes or the variance in electricity consumption of different household types and sizes. Using all these factors creates a much more complex situation for scenario modelling. Because the main target of this research was to assess the Open Asset dataset, these variables were neglected to simplify the electricity consumption. Also the future expectation of the growth of electrical vehicles was neglected.

Thirdly the future prognosis is briefly touched in the theoretical and contextual framework but is not worked out in the analyses and results. The idea of a future prognosis was to identify possible changes in the electricity consumption in the area. Factors such as more electrical vehicles, population decline, and household size decline all affect the electricity consumption. Including this future prognosis would create more complexity and therefore it was considered as out of the scope of the project.

Fourthly most variables that have been used in the suitability analysis for solar panels and wind mills were regarded as binary variables. This meant that a slope of 24° was regarded as unsuitable while a slope of 25° was seen as suitable. This could have been perfected to a suitability analysis with multiple classes to identify. In addition to that for the placement of solar panels a slope was required according to the analysis. However, placing tilted solar panels on flat roofs is also a common practice to maximize the production of the panels. This option was also neglected in the research.

Finally, the total electricity consumption that was used to identify possibilities for an energy transition was based on the information available in the Open Asset data. This information was only about the residential and commercial sector in the area. The total electricity consumption in the area is expected to be much higher; this would mean that the amount of wind mills and solar panels should be higher as well. However, including this was regarded as unnecessary since it would not change the outcome of the main aim of the research, assessing the Open Asset dataset.

7.2.2 External discussion

When comparing this research in the wider academic and societal context some similarities and differences can be found. The main aim of the energy transition, reaching 100% renewable electricity production is commonly used in energy transition scenario modelling. The reports that have been used in this research to identify common characteristics all aimed on 100% renewable energy. A 100% renewable produced electricity system in the Netherlands might be a bit too utopian due to the low potential of water energy, which is the least weather dependent of the three green renewable sources. Elliston (2012) also argued that relying on solely renewable sources is unachievable due to the inconsistency in production.

Another big theme discussed in this research is the use of open data. The aim of this research was to assess an open dataset provided by a large net operator in the Netherlands. In the 21st century open data and transparency in the commercial sector have become more and more important. Instead of confidential and protected data, more companies share an anonymized version of their data for the public.

In the field of energy transitions the studies are primarily theoretical and involve mostly calculations on electricity production and consumption. This is often very detailed. However, there is currently limited research done on the mix of the electricity grid and smart grid enhancements and the energy transitions. In the field of GIS and Energy transitions are some studies done, however they There is enough academic literature that describes which potential there is for these transitions, however the more detailed and very large case studies often performed by commercial parties involve these spatial components to a certain limit.

7.3 Recommendations

For future research several recommendations can be made. First of all the similar research can be done with a different dataset. This research contained the open asset dataset of Enexis. However there might be other open data sets available or easily accessible that can be studies with the same aim. In addition to that a net operator in the Netherlands might be willing to share a part of their dataset for a certain research.

Secondly a similar study can be performed given a different scenario. In this research the aim was to assess the data according to an energy transition. This was proven to be not possible to the full extend with the open asset data set. However a different scenario with other variables and demands might fit the open asset dataset better and might give different results.

Finally a more extensive research could be performed in which the ignored variables from the constraints of the research will be taken in to account. Due to the high dependency on favorable weather conditions for the electricity production in this research, the defined electricity production and consumption might give a skewed conceptualization of the reality. In a future research a more detailed work out of the various spatial and temporal variables could be included.

REFERENCES

AHN. (2017). *Actueel Hoogtebestand Nederland - Over AHN*. [online] Available at: http://www.ahn.nl/common-nlm/over-ahn.html [Accessed 6 Jun. 2017].

Akuru, U., Onukwube, I., Okoro, O. and Obe, E. (2017). Towards 100% renewable energy in Nigeria. *Renewable and Sustainable Energy Reviews*, 71, pp.943-953.

AllesOverZonnepanelen. (2012). *Zonnepanelen en dakhelling - Optimale hellingshoek*. [online] Available at: http://www.allesoverzonnepanelen.nl/voorwaarden/dakhelling/ [Accessed 6 Jun. 2017].

Altalink. (2017). *Alberta's Electrical Transmission System*. [online] Available at: http://www.altalink.ca/albertas-electricity-system/overview.cfm [Accessed 6 Jun. 2017].

AT&T (https://www.business.att.com/enterprise/Service/internet-of-things/smart-cities/iot-smart-grid/)

Bayindir, R., Colak, I., Fulli, G. and Demirtas, K. (2016). Smart grid technologies and applications. *Renewable and Sustainable Energy Reviews*, 66, pp.499-516.

Blaxter, L., Hughes, C. and Tight, M. (2010). How to research. Maidenhead: Open University Press/McGraw-Hill Education.

Boritz, J. (2011). IS practitioners' views on core concepts of information integrity. *International Journal of Accounting Information Systems*, 6(4), pp.260-279.

Bridge, G., Bouzarovski, S., Bradshaw, M. and Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy*, 53, pp.331-340.

BT Duurzaam. (n.d.). *Dakrichting en dakhelling - Zonnepanelen in uw regio*. [online] Available at: http://www.btduurzaam.nl/artikel/dakrichting-en-dakhelling/ [Accessed 6 Jun. 2017].

Carr, G. (2012). *Sunny uplands - Alternative energy will no longer be alternative*. [online] Economist. Available at: http://www.economist.com/news/21566414-alternative-energy-will-no-longer-be-alternative-sunny-uplands [Accessed 5 Jun. 2016].

Centers for Disease Control and Prevention. (2009). Quality assurance standards for HIV counseling, testing, and referral data. Atlanta: Department of Health and Human Services, Centers of Disease Control and Prevention.[online] Available at: http://www.cdc.gov/hiv/testing/resources/guidelines/quas/overview.htm#link4 [Accessed 5 Jun. 2017].

Charabi Y, & A. Gastli (2011), PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. Renewable Energy 36:9, pp. 2554–61.

Child, M. and Breyer, C. (2016). The Role of Energy Storage Solutions in a 100% Renewable Finnish Energy System. *Energy Procedia*, 99, pp.25-34.

Clifford, N. and Valentine, G. (2013). Key methods in geography. London: SAGE.

Connolly, D., Lund, H., Mathiesen, B. and Leahy, M. (2011). The first step towards a 100% renewable energy-system for Ireland. *Applied Energy*, 88(2), pp.502-507.

Danish Energy Agency. (2014). Spliid, Iben. Stamdataregister for vindmøller – November 2014. HTML-spreadsheet, column E. Danish Energy Agency

De Volkskrant. (2010). Daling stroomverbruik voorbij. [online] Available at: http://www.volkskrant.nl/economie/daling-stroomverbruik-voorbij~a973241/ [Accessed 5 Jun. 2017].

DeZonnepaneelExpert. (n.d.). *Hellingshoek zonnepanelen*. [online] Available at: http://www.dezonnepaneelexpert.nl/informatie-zonnecel-informatie-zonnepaneel-informatie-zonne/hellingshoek-zonnepanelen/ [Accessed 6 Jun. 2017].

Diamandis, P. (2016). *Disrupting Solar*. [online] The Huffington Post. Available at: http://www.huffingtonpost.com/peter-diamandis/disrupting-solar_b_9865216.html [Accessed 5 Jun. 2016].

DTE Energy. (2017). *About Electric Service - From Power Plant to You*. [online] Available at: https://www2.dteenergy.com [Accessed 6 Jun. 2017].

DutchSolarEnergy. (2015). *Orientatie Zonnepanelen*. [online] Available at: http://www.dutchsolarenergy.nl/cms/wp-content/uploads/2015/02/Orientatie-zonnepanelen.jpg [Accessed 6 Jun. 2017].

El Baroudy, A. (2016), Mapping and evaluating land suitability using a GIS-based model. CATENA 140, pp. 96–104.

Energieleveranciers. (2016). *Alle energieleveranciers in Nederland*. [online] Available at: https://www.energieleveranciers.nl/energieleveranciers [Accessed 5 Jun. 2016].

Enexis Open Asset Data (2016). Data from: All assets above and below ground level., electronic data set, *Enexis open data.* [online] Available at: https://www.enexis.nl/over-enexis/open-data [Accessed 8 Oct. 2016].

Enexis. (2016). *Enexis introduceert kengetallen-app | Enexis*. [online] Available at: https://www.enexis.nl/over-enexis/nieuws/Enexis-introduceert-kengetallen-app [Accessed 6

Jun. 2017].

Enexis. (n.d.). *Open data van Enexis | Enexis*. [online] Available at: https://www.enexis.nl/over-enexis/open-data [Accessed 6 Jun. 2017].

ESRI. (2017). *ArcMap Resources | ArcMap*. [online] Available at: http://www.esri.com/en/arcgis/products/arcgis-pro/resources/arcmap-resources [Accessed 18 Jun. 2017].

Eurandom. (2012). *Endinet: Future Challenges in the Electricity Grid Infrastructure*. [online] Available at: http://www.eurandom.nl/events/workshops/2012/SWI_2012/Problems/Problems_Endinet.html [Accessed 6 Jun. 2017].

European Commission. (2000). *Lisbon strategy - towards a green and innovative economy*. [online] Available at: http://ec.europa.eu/archives/growthandjobs_2009/ [Accessed 9 Nov. 2016].

European Commission. (2010). *Europe 2020 – Europe's growth strategy*. [online] Available at: http://ec.europa.eu/europe2020/index_en.htm [Accessed 9 Nov. 2016].

Faller, F. (2015). A practice approach to study the spatial dimension of the energy transition. *Environmental Innovation and Societal Transitions,* 19, pp.85-95.

Fransman, R. (2014). *Word rijk, koopt allen zonnepanelen*. [online] ZonBespaart. Available at: http://www.zonbespaart.nl/nieuws.html [Accessed 6 Jun. 2017].

German Ministery of Economic Affairs and Energy (2016) *"Federal Ministry for Economic Affairs and Energy (Germarny),Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, Stand August 2016"*

Grin, J., Rotmans, J. and Schot, J. (2011). On patterns and agency in transition dynamics: Some key insights from the KSI programme. *Environmental Innovation and Societal Transitions*, 1(1), pp.76- 81.

Guba, E. G., and Lincoln, Y. S. (1981). Effective evaluation: Improving the usefulness of evaluation results through responsive and naturalistic approaches. San Francisco, CA: Jossey-Bass.

Haas, R., Watson, J. and Eichhammer, W. (2008). Transitions to sustainable energy systems—Introduction to the energy policy special issue. *Energy Policy*, 36(11), pp.4009-4011.

Harder, C., Ormsby, T. and Balstrøm, T. (2011). *Understanding GIS*. 1st ed. Redlands, California: Esri Press.

Heywood, I., Cornelius, S., & Carver, S. (2002). *Geographical Information Systems* (second edi.). Harlow, Essex, England: Pearson Education Limited.

Higgins, M. (2013). *Innovative Technologies - Wind energy*. 1st ed. North Mankato, Minnesota: ABDO Publishing Company.

HoogspanningsNet. (2016). *380 kV - HoogspanningsNet*. [online] Available at: http://www.hoogspanningsnet.com/hetnet/380kv/ [Accessed 9 Nov. 2016].

Howell, S., Rezgui, Y., Hippolyte, J., Jayan, B. and Li, H. (2017). Towards the next generation of smart grids: Semantic and holonic multi-agent management of distributed energy resources. *Renewable and Sustainable Energy Reviews*, 77, pp.193-214.

International Bureau of Weights and Measures (2006). *The International System of Units (SI)*. p.118.

International Electrotechnical Commission. (2016). *Smart Grid - Optimal Electricity Delivery - Challenges*. [online] Available at: http://www.iec.ch/smartgrid/challenges/ [Accessed 10 Nov. 2016].

Johnson, B. and Christensen, L. (2008). Educational Research: Qualitative, Quantitative and Mixed Approaches. London: SAGE

Jones, D. (1991). Electrical engineering: the backbone of society. *IEE Proceedings A Science, Measurement and Technology*, 138(1), p.1.

Kadaster. (2017a). *BAG - Wat is de Bag?*. [online] Available at: https://www.kadaster.nl/wat-is-de-bag [Accessed 6 Jun. 2017].

Kadaster. (2017b). *BGT*. [online] Available at: https://www.kadaster.nl/bgt [Accessed 6 Jun. 2017].

Kern, F. and Rogge, K. (2016). The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes?. *Energy Research & Social Science*, 22, pp.13-17.

Klimaatmonitor. (2015). *Hernieuwbare Energie - Dashboard Klimaat - Tubbergen*. [online] Available at: https://klimaatmonitor.databank.nl/dashboard/Hernieuwbare-Energie--Hernieuwbare_energie/ [Accessed 9 Jun. 2017].

Kneale, P. (2011). Study skills for geography, earth and environmental science students. London: Hodder Education.

KNMI. (1992). *Zonne-instraling in Nederland. Koninklijk Nederlands Meteorologisch Instituut. [online] Available at:* bibliotheek.knmi.nl/knmipubDIV/Zonnestraling_in_Nederland.pdf [Accessed 3 Jun. 2017].

Köktürk, G. and Tokuç, A. (2017). Vision for wind energy with a smart grid in Izmir. *Renewable and Sustainable Energy Reviews*, 73, pp.332-345.

Krajačić, G., Duić, N. and Carvalho, M. (2011). How to achieve a 100% RES electricity supply for Portugal?. *Applied Energy*, 88(2), pp.508-517.

Lawrence, T., Boudreau, M., Helsen, L., Henze, G., Mohammadpour, J., Noonan, D., Patteeuw, D., Pless, S. and Watson, R. (2016). Ten questions concerning integrating smart buildings into the smart grid. *Building and Environment*, 108, pp.273-283.

Lehmann, H. (2003). *Energy Rich Japan*. Aachen, Germany: Institute for Sustainable Solutions and Innovations.

Lesser, J. (2014). *America's Electricity Grid: Outdated or Underrated?*. [online] The Heritage Foundation. Available at: http://www.heritage.org/environment/report/americas-electricity-grid-outdated-or-underrated [Accessed 6 Jun. 2017].

Lienert, P., Suetterlin, B. and Siegrist, M. (2015). Public acceptance of the expansion and modification of high-voltage power lines in the context of the energy transition. *Energy Policy*, 87, pp.573-583.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Science and Systems* (fourth edi.). Hoboken, NJ: John Wiley & Sons.

Mansell, D. (2017). *Wivey Energy & Solar Power*. [online] Wivey Energy & Solar Power. Available at: https://wiveysolar.files.wordpress.com [Accessed 6 Jun. 2017].

Markard, J., Raven, R. and Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), pp.955-967.

Martin, J. (2013). *The impact of rising wholesale fuel costs on Queensland's electricity prices*. [online] SolarChoice. Available at: https://www.solarchoice.net.au/blog/impact-of-rising-fossil-fuel-costs-on-qld-electricity-prices/ [Accessed 6 Jun. 2017].

Mason, I., Page, S. and Williamson, A. (2010). A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources. *Energy Policy*, 38(8), pp.3973-3984.

Meyers, J. and Meneveau, C. (*2011). Optimal turbine spacing in fully developed wind farm boundary layers. Wind Energy*, 15(2), pp.305-317.

Morvaj, B., Knezović, K., Evins, R. and Marinelli, M. (2016). Integrating multi-domain distributed energy systems with electric vehicle PQ flexibility: Optimal design and operation scheduling for sustainable low-voltage distribution grids. *Sustainable Energy, Grids and Networks*, 8, pp.51-61.

Müller, M., Viernstein, L., Truong, C., Eiting, A., Hesse, H., Witzmann, R. and Jossen, A. (2017). Evaluation of grid-level adaptability for stationary battery energy storage system applications in Europe. *Journal of Energy Storage*, 9, pp.1-11.

NOS. (2015). *Te veel zonnepanelen in Groningen*. [online] Available at: http://nos.nl/artikel/2118256-te-veel-zonnepanelen-in-groningen.html [Accessed 9 Nov. 2016].

NWEA. (2016). *Windmolens en slagschaduw - NWEA Wind*. [online] Available at: http://www.nwea.nl/windenergie/infographics-land/1016-windmolens-en-slagschaduw [Accessed 8 Jun. 2017].

O'Conner, P. (2010). *Energy Transitions*. The Pardee Papers. Boston: Boston University.

Organization for Economic Co-operation and Development. (2003). Quality framework and guidelines for OECD Statistical activities, version 2003/1. [online] Available at: http://www.oeced.org/dataoecd/26/42/21688835.pdf [Accessed 5 Jun. 2017]

Overheid. (2017). *Basisregistratie Grootschalige Topografie (BGT) - Data.overheid.nl*. [online] Available at: https://data.overheid.nl/data/dataset/basisregistratie-grootschalige-topografie-bgt [Accessed 6 Jun. 2017].

Physics. (2014). *How do solar cells work?| Explore | physics.org*. [online] Available at: http://www.physics.org/article-questions.asp?id=51 [Accessed 8 Jun. 2017].

Pierri, E., Binder, O., Hemdan, N. and Kurrat, M. (2017). Challenges and opportunities for a European

HVDC grid. *Renewable and Sustainable Energy Reviews*, 70, pp.427-456.

Provoost, B. (2016). *Buurt plaatst zo veel zonnepanelen dat extra cabine nodig is*. [online] Het Nieuwsblad. Available at: http://www.nieuwsblad.be/cnt/blbpr_02296899 [Accessed 9 Nov. 2016].

PureSolar. (2013). *Wat is de optimale oriëntatie/dakhelling voor een zonnepaneel systeem? - Veelgestelde vragen*. [online] Available at: http://www.puresolar.nl/veelgestelde-vragen/wat-is-de-optimale-ori%C3%ABntatie-dakhelling-voor-een-zonnepaneel-systeem [Accessed 6 Jun. 2017].

Radhakrishna, R. B., and Doamekpor, P. (2008). Strategies for generalizing findings in survey research. *Journal of Extension* [On-line] 46(2), Article 2TOT1.

Radhakrishna, R. B., Tobin, D., Brennan, M. and Thompson, J. (2012). Ensuring Data Quality in Extension Research and Evaluation Studies. *Journal of Extension*, 50(3).

Redlinger, R., Andersen, P. and Morthorst, P. (2002). *Wind energy in the 21st century*. 1st ed. New York: Palgrave.

Rhodes, R. (2007). *Energy Transitions: A Curious History*. Stanford: Center for International Security and Cooperation.

Rijksdienst voor Ondernemend Nederland (2016). *Slagschaduw bij windturbines*. Duurzaam, Agrarisch, Innovatief en Internationaal ondernemen. [online] Utrecht, The Netherlands: Rijksdienst voor Ondernemend Nederland. Available at: https://www.rvo.nl/sites/default/files/2016/05/Factsheet%20Slagschaduw.PDF [Accessed 9 Jun. 2017].

RIVM. (2016). *Geluid van windturbines nader bekeken - RIVM*. [online] Available at: http://www.rivm.nl/Documenten_en_publicaties/Algemeen_Actueel/Nieuwsberichten/2015/Geluid_van_windturbines_nader_bekeken [Accessed 8 Jun. 2017].

RVO. (2017). *Geluid | RVO.nl*. [online] Available at: http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/milieu-en-omgeving/geluid [Accessed 8 Jun. 2017].

Schoenmakers, H. (2017). *Zonnepanelen op plat dak*. [online] VoltaSolar. Available at: https://www.bespaarbazaar.nl/kenniscentrum/ontwerp/zonnepanelen-op-plat-dak/ [Accessed 6 Jun. 2017].

Schootstra, S. (2016). *Groeispurt opgesteld PV-vermogen bij CertiQ*. [online] EnergieBusiness. Available at: http://www.energiebusiness.nl/2016/02/09/groeispurt-opgesteld-vermogen-pv-certiq/ [Accessed 9 Nov. 2016].

Sharma, K. and Mohan Saini, L. (2015). Performance analysis of smart metering for smart grid. *Renewable and Sustainable Energy Reviews.* pp.720-735

Siderea. (2017). *De ideale hellingshoek voor zonnepanelen.*. [online] Available at: http://www.siderea.nl/artikelen/hellingshoek1/hellingshoek1.html [Accessed 6 Jun. 2017].

SolarPanelInstallations. (2011). *Maximizing solar panel output - Slope*. [online] Available at:

http://www.allesoverzonnepanel.nl/wp-content/uploads/2011/01/maximale-opbrengst-is-afhankelijk-van-dakorientatie-en-dakhelling.jpg [Accessed 6 Jun. 2017].

Statistics Netherlands, (2015). *Electriciteit in Nederland*. Heerlen, The Netherlands: Statistics Netherlands.

Statistics Netherlands. (2016a). *Motorvoertuigenpark; inwoners, type, regio, 1 januari*. [online] Available at: http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=7374hvv [Accessed 8 Nov. 2016].

Statistics Netherlands. (2016b). *Bevolking, huishoudens en bevolkingsontwikkeling; vanaf 1899*. [online] Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37556 [Accessed 8 Nov. 2016].

Statistics Netherlands. (2016c). *Energieverbruik Huishoudens; energiedragers*. [online] Available at: http://statline.cbs.nl/Statweb/selection/?DM=SLNL&PA=82375NED&VW=T [Accessed 9 Nov. 2016].

Statistics Netherlands. (2016d). *Hernieuwbare elektriciteit; productie en vermogen*. [online] Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82610NED [Accessed 9 Nov. 2016].

Statistics Netherlands. (2016e). *Aardgas en elektriciteit, gemiddelde prijzen van eindverbruikers*. [online] Available at: http://statline.cbs.nl/Statweb/selection/?DM=SLNL&PA=81309NED [Accessed 10 Nov. 2016].

Statistics Netherlands. (2016f). *Meer hoge en efficiente windmolens op land*. [online] Available at: https://www.cbs.nl/nl-nl/nieuws/2016/39/meer-hoge-en-efficiente-windmolens-op-land [Accessed 2 Jun. 2016].

Tummala, A., Velamati, R., Sinha, D., Indraja, V. and Krishna, V. (2016). A review on small scale wind turbines. *Renewable and Sustainable Energy Reviews*, 56, pp.1351-1371.

United Nations, 2010. Framework convention on climate change. Report of the Conference of the Parties on its Sixteenth Session, held in Cancun from 29 November to 10 December 2010, United Nations, Cancun.

United Nations. (2014). *Kyoto Protocol*. [online] Available at: http://unfccc.int/kyoto_protocol/items/2830.php [Accessed 9 Nov. 2016].

Vale, S. (2010). Statistical data quality in the UNECE, 2010 version. Statistical Division, United Nations. [online] Available at: http://unstats.un.org/unsd/dnss/docs-nquaf/UNECE-quality%20Improvement%20Programme%202010.pdf [Accessed 6 Jun. 2017].

Van Loenen, B., Kulk, S. and Ploeger, H. (2016). Data protection legislation: A very hungry caterpillar. *Government Information Quarterly*, 33(2), pp.338-345.

Van Sluis, B. (2016). *38 klachten over uitval door te veel aan zonnepanelen Groningen*. [online] Dagblad van het Noorden. Available at: http://www.dvhn.nl/economie/38-klachten-over-uitval-door-te-veel-aan-zonnepanelen-Groningen-21563818.html [Accessed 9 Nov. 2016].

Wikimedia. (2008). *Electricity Grid Scheme*. [online] Available at: https://commons.wikimedia.org/wiki/File:Electricity_grid_schema-_lang-en.jpg [Accessed 6 Jun.

2017].

Wikipedia. (2017). *Electrical grid*. [online] Available at: https://en.wikipedia.org/wiki/Electrical_grid [Accessed 6 Jun. 2017].

Wright, M. and Hearps, P. (2010). *Zero Carbon Australia Stationary Energy Plan*. Beyond Zero Emissions. Melbourne: The University of Melbourne Energy Research Institute.

Zerauto. (2012). *'Hoeveel energie verbruikt een elektrische auto?'*. [online] Available at: http://www.zerauto.nl/2012/04/26/hoeveel-energie-verbruikt-een-elektrische-auto/ [Accessed 9 Nov. 2016].

APPENDICES

Appendix I – Detailed overview of individual datasets

#	Type	Contains	Size	Attributes
1	Point	Electrical vehicle charging point	142 kB	665 (points)
		This point layer dataset contains all points where electrical vehicles can be charged. These points are connected with the low voltage connection cables(6) network in the area.		
2	Point	Multi-storey connection point	18,080 kB	79,646 (points)
		This point layer dataset contains all connection points where multi-storey buildings are connected. Often these are not connected to the low voltage connection cables(6), but just floating near the network.		
3	Point	Service connection point	567,649 kB	2,522,883 (points)
		This point layer dataset contains all service connection points. These points resemble the residential and commercial meter boxes in the houses. In most cases these are connected to the low voltage connection network(6). However, this is not always the case, in some cases these points are directly connected to a connection box(9 and 10), distribution box(11 and 12) or technical building(13 and 14).		
4	Point	Street furniture	11,164 kB	44,298 (points)
		This point layer dataset contains all constructions in the public space that require electricity. Among these are bus stops, commercial billboards, road signs and traffic lights. They are connected to the low voltage connection cable(6).		
5	Point	Street light connection	312,754 kB	1,376,118 (points)
		This point layer dataset contains all points that resemble the street lights. These are all connected to low voltage 240V connection cables(6).		
6	Polyline	Low voltage connection cable	1,777,196 kB	
		This polyline layer contains all the connection cable of the low voltage network. These are the last parts of the network between the distribution (low voltage) and the service connection points.		
7	Polyline	Low voltage distribution cable	1,143,916 kB	
		This polyline layer contains all the distribution cables of the low voltage network. The voltage cables is either 240V or 400V These cables all originate from connection boxes(9 and 10), distribution boxes(11 and 12) or in some cases technical buildings(13 and 14).		
8	Polyline	Middle voltage distribution cable	348,881 kB	
		This polyline layer contains all the distribution cables with middle voltage of 3000V or 10000V. These cables are only connected with the technical buildings(13 and 14).		
9	Point	Connection box (point)	10,078 kB	62,652 (points)
		This point layer in the dataset contains all connection boxes. Connection boxes are the grey little plastic boxes next to the road in which the power is divided over more or less cables. Only 400V and 240V distribution cables(7) are connected to these boxes. In some cases a connection box is directly connected to a service connection point(3).		
10	Polygon	Connection box (polygon)	16,924 kB	62,652 (polygons)
		This polygon layer shows the same information as the previous (point) layer. However, in this layer the exact outlines of the connection boxes are drawn. In and out coming cables of both the low voltage connection and distribution grid stop where the polygon starts.		

11	Point	Distribution box (point)	10,406 kB	66,275 (points)
		This point layer in the dataset contains all distribution boxes. Distribution boxes are often the green little boxes next to the road in which the power is divided over more or less cables. Only 400V and 240V distribution cables(7) are connected to these boxes. In some cases a distribution box is directly connected to a service connection point(3).		
12	Polygon	Distribution box (polygon)	19,080 kB	66,275 (polygons)
		This polygon layer shows the same information as the previous (point) layer. However, in this layer the exact outlines of the distribution boxes are drawn. In and out coming cables of both the low voltage connection and distribution grid stop where the polygon starts.		
13	Point	Technical building (point) (low voltage)	8,320 kB	51,354 (points)
		This point layer in the dataset contains all the technical buildings. Technical buildings are the large concrete buildings in neighborhoods where the power is cascaded onto a lower voltage. This is mostly from 10000V to 400V or 240V. The technical buildings are attached to the low voltage distribution network(7) and the middle voltage distribution network(8). In rare cases the technical buildings is directly attached to a service connection point(3).		
14	Polygon	Technical building (polygon) (low voltage)	15,213 kB	51,354 (polygons)
		This polygon layer shows the same information as the previous (point) layer. However, in this layer the exact outlines of the technical buildings are drawn. In and out coming cables of both the low and middle voltage grid stop where the polygon starts.		
15	Point	Technical building (point) (middle voltage)	8,425 kB	51,369 (points)
		This point layer is a replica of layer thirteen. The points in this layer overlap exactly the points in layer 13. However this layer contains 15 extra points.		
16	Polygon	Technical building (polygon) (middle voltage)	15,429 kB	51,369 (polygons)
		This polygon layer shows the same information as the previous (point) layer. However, in this layer the exact outlines of the technical buildings are drawn. In and out coming cables of both the low and middle voltage grid stop where the polygon starts.		
17	Excel	Metadata attributes	40 kB	
		In this excel file the metadata about the various attributes that are used in the other datasets are explained. Among these attributes are for example; label, vertical position, geo-accuracy, description and source reference.		
18	Excel	Metadata objects	14 kB	
		In this excel file all the different layers dataset are briefly explained. Some information is given of the use, connectivity and GIS application name.		

Appendix II – Disclaimer Open Asset Data

Disclaimer Open Data Enexis

Algemeen:

De voorwaarden van deze Disclaimer zijn van toepassing op de internetsite https://www.enexis.nl/over-enexis/open-data met daarop gepubliceerde datasets van Enexis B.V. Enexis B.V. is gevestigd op adres Magistratenlaan 116, Den Bosch (hoofdkantoor) en is ingeschreven in het Handelsregister van de KvK onder nummer 17131139.

Gebruik van deze internetsite:

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Gebruiksvoorwaarden:

De gegevens/data worden beschikbaar gesteld onder de volgende voorwaarden:

- Enexis behoudt zijn intellectuele eigendomsrechten (zoals het databankenrecht).

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2. De informatie die op of via deze internetsite wordt aangeboden.

3. Het onderscheppen, wijzigen of oneigenlijk gebruik van informatie die aan Enexis of aan u wordt gezonden.
4. De werking of het niet-beschikbaar zijn van deze internetsite.
5. Misbruik van deze internetsite.
6. Verlies van gegevens.
7. Het downloaden of gebruiken van software die via deze internetsite beschikbaar wordt gesteld.
8. Aanspraken van derden in verband met gebruik van deze internetsite. De uitsluiting van aansprakelijkheid strekt mede ten gunste van bestuurders en medewerkers van Enexis.
9. Een grondroerder die overgaat tot mechanische grondroering dient daartoe een KLIC-melding te doen. De informatie via open data kan noch formeel, noch materieel als vervanging dienen voor die wettelijke verplichting. De aanbieding van informatie inzake open data van aan Enexis toebehorende assets geeft geen enkele garantie voor aanwezigheid en/of locatie van de op grond van KLIC-melding noodzakelijke gegevens.

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Op deze internetsite en de Disclaimer is Nederlands recht van toepassing. Alle geschillen uit hoofde van of in verband met deze Disclaimer zullen bij uitsluiting worden voorgelegd aan de bevoegde rechter in Nederland. Indien anderstalige versies van de Disclaimer of de internetsite discrepanties vertonen of tot interpretatieverschillen leiden, is de versie in de Nederlandse taal leidend.

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Appendix III Ethical Aspects

III.a In research it is important to behave ethically and protect personal data as much as possible. Especially when working with of creating open data it is important that it is not possible to trace the data back to the exact owner. Clifford and Valentine (2011) created three pillars about why ethical research is important and should be performed as such. The three pillars are:

1. *"Ethical behaviour protects the right of individuals, communities and environments involved in, or affected by our research."* (Clifford and Valentine, 2011, p.36)

The first pillar constructed by Clifford and Valentine and is there to protect the rights of the subject of the study. Privacy statements and data copyrights are becoming more and more important in the 21th century, since everything that is made digital is very hard to destroy or erase forever. As a researcher it is very important to behave ethically and to protect these values for the individuals, communities or environments that are being studied.

2. *"Ethical behaviour helps assure a favourable climate for the continued conduct of scientific inquiry"* (Clifford and Valentine, 2011,p.36)

Secondly ethical behavior and taking the first point into account is important for building a favorable climate for scientific inquiry. It is very important that the subjects that are being studied trust the researchers and their aim. When this is done correctly trust is built between subjects and researchers. This is very important to get reliable and viable results or to study very personal and sensitive topics.

3. *"Growing public demands for accountability and the sentiment that institutions such as universities must protect themselves legally from the unethical or immoral actions of a student or employee mean there is greater emphasis on acting ethically than ever before."*(Clifford and Valentine, 2011, p.36)

The third pillar reflects on the position of the researcher or research institution in general. Behaving unethical as a researcher or institution is a costly thing. In the modern time social media and globalization cause a big pressure on ethical behavior. Acting not ethical is being punished by online shaming of the researcher or institute damaging their name. This has happened in the past with researches where subjects were not treated well or their data was shared with other groups. For these reasons the emphasis on ethical research is greater than before.

III.b Ethics in this research

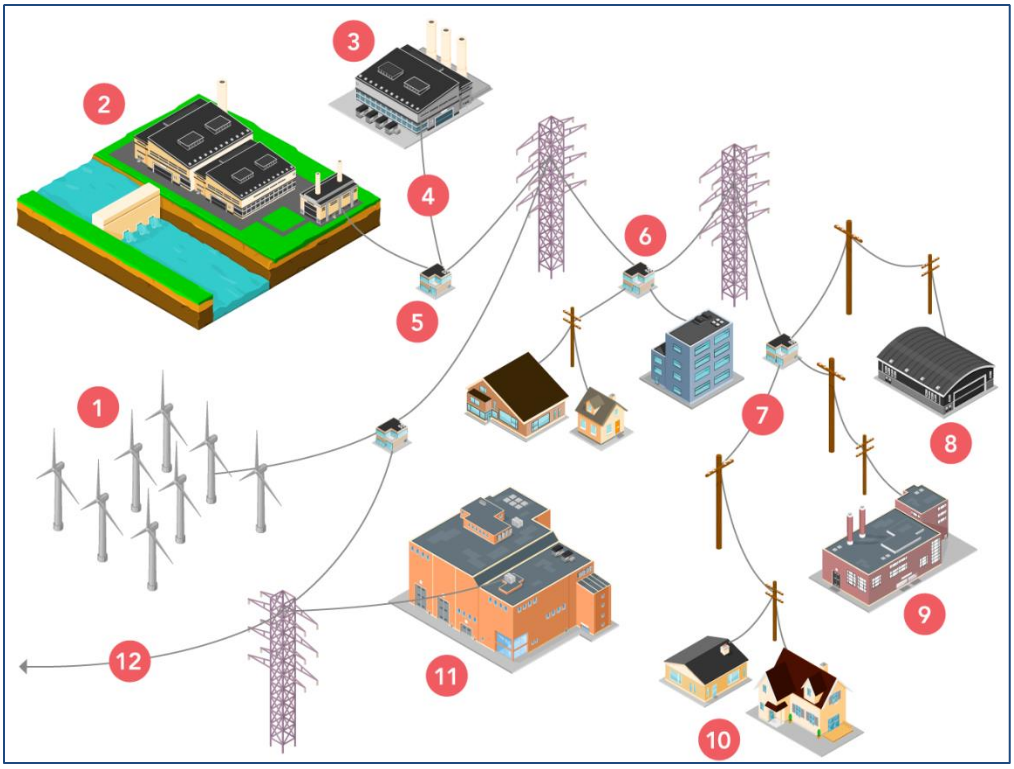
In this research personal and non-personal data from various sources have been used. The Open Asset dataset of Enexis was anonymized in such a way that the actual service points (electricity boxes in the houses) had only a spatial identification and not a personal or one linked to an address. In addition to that the information provided by Enexis regarding the electricity consumption was de-personalized to a P6-level (only zip codes with 4 numbers and 2 letters, for example 7623NE) (Enexis, n.d.).

Data of the Statistics Netherlands that has been used is often anonymized in the same way. The population data for example is available on both P6-level or on neighborhood level. But both datasets make it impossible to identify individual households or persons. The BAG dataset from the Dutch cadaster that has been used was used without the exact addresses or zip codes attached to them. All these precautions were taken in order to protect the privacy of the subjects

III.c Mosaic effect

Even when all the data has been anonymized or has been simplified to a more generic dataset the mosaic effect can happen. This means that all the data can be compared and it is still possible to trace the data back to the individual subject. In case of this research, it was impossible to trace back the electricity consumption all the way to every single household, since electricity consumption data is provided on a much 'higher' level. Even with more data about households, amount of houses and such it is impossible to trace back the exact number. In addition to that, in this report and its appendices the data that is presented if of such a scale that for readers it is impossible to 'mosaic' the data back to household level (van Loenen, Kulk and Ploeger, 2016)

Appendix III – Eleven electricity grid concepts



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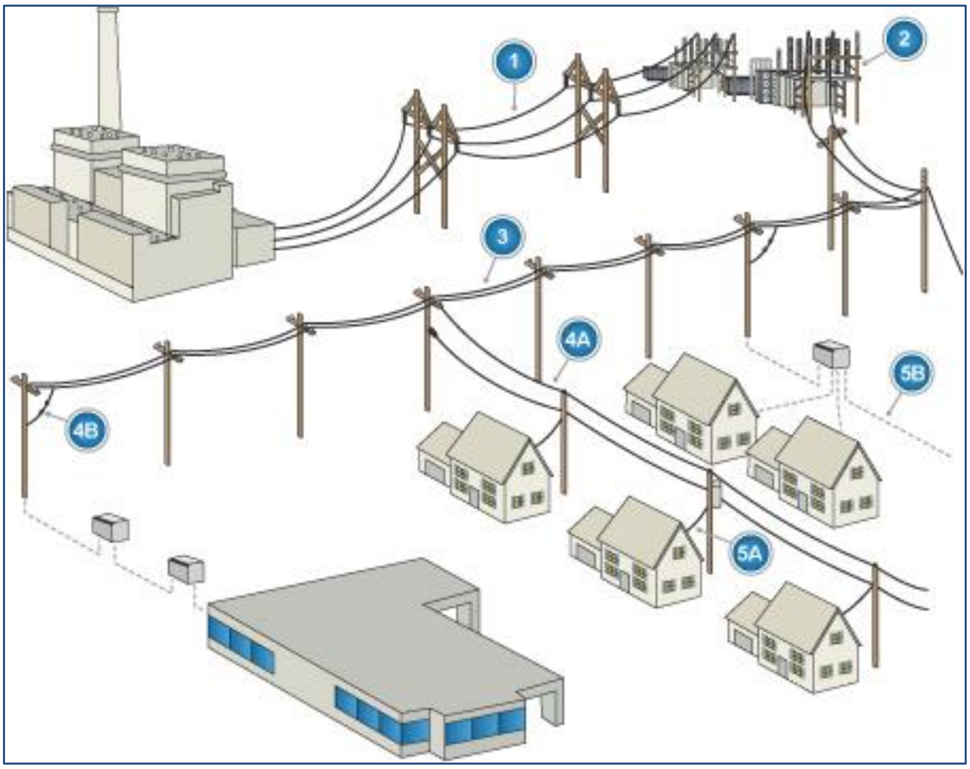
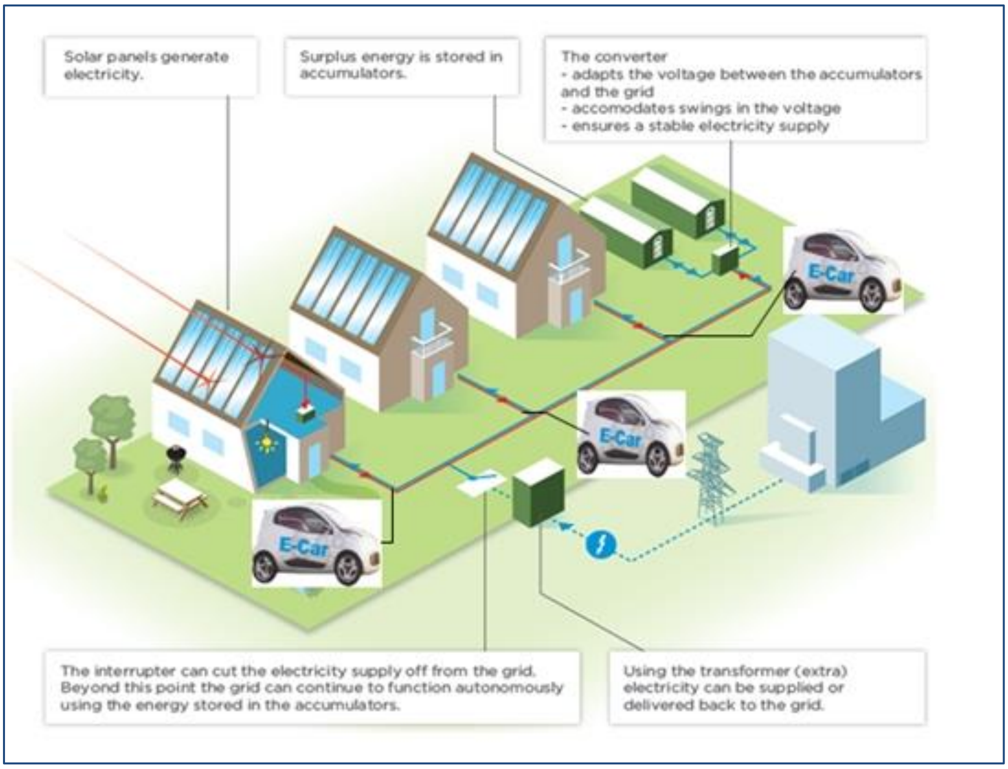
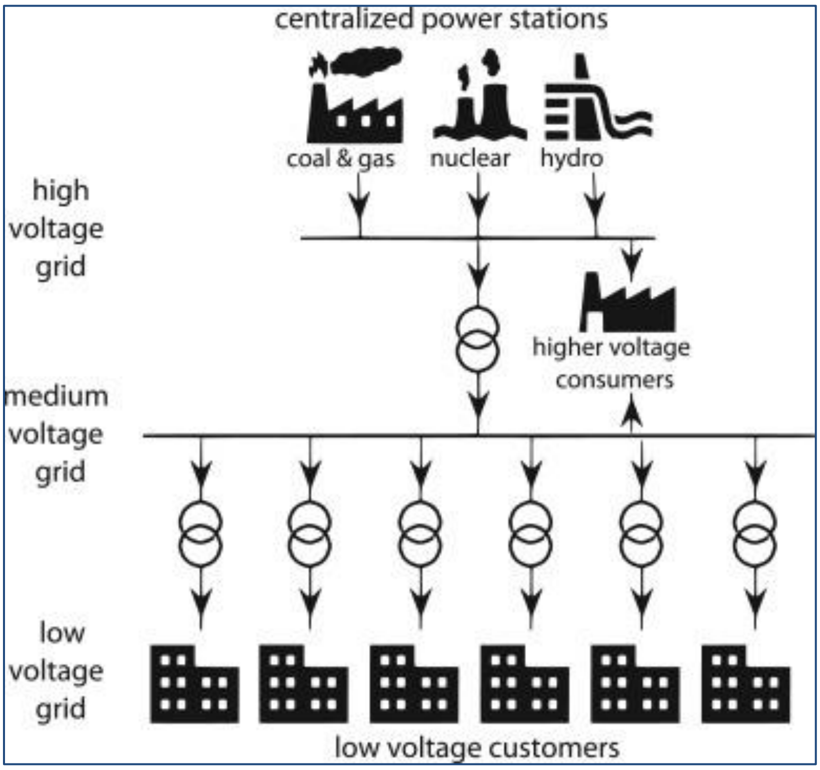


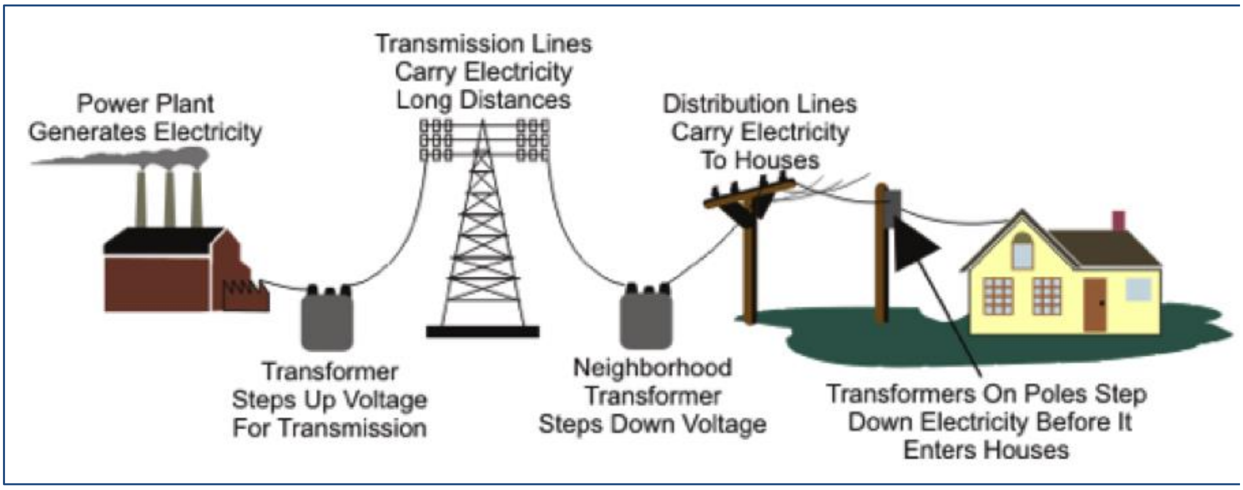
DTE Energy (2017)



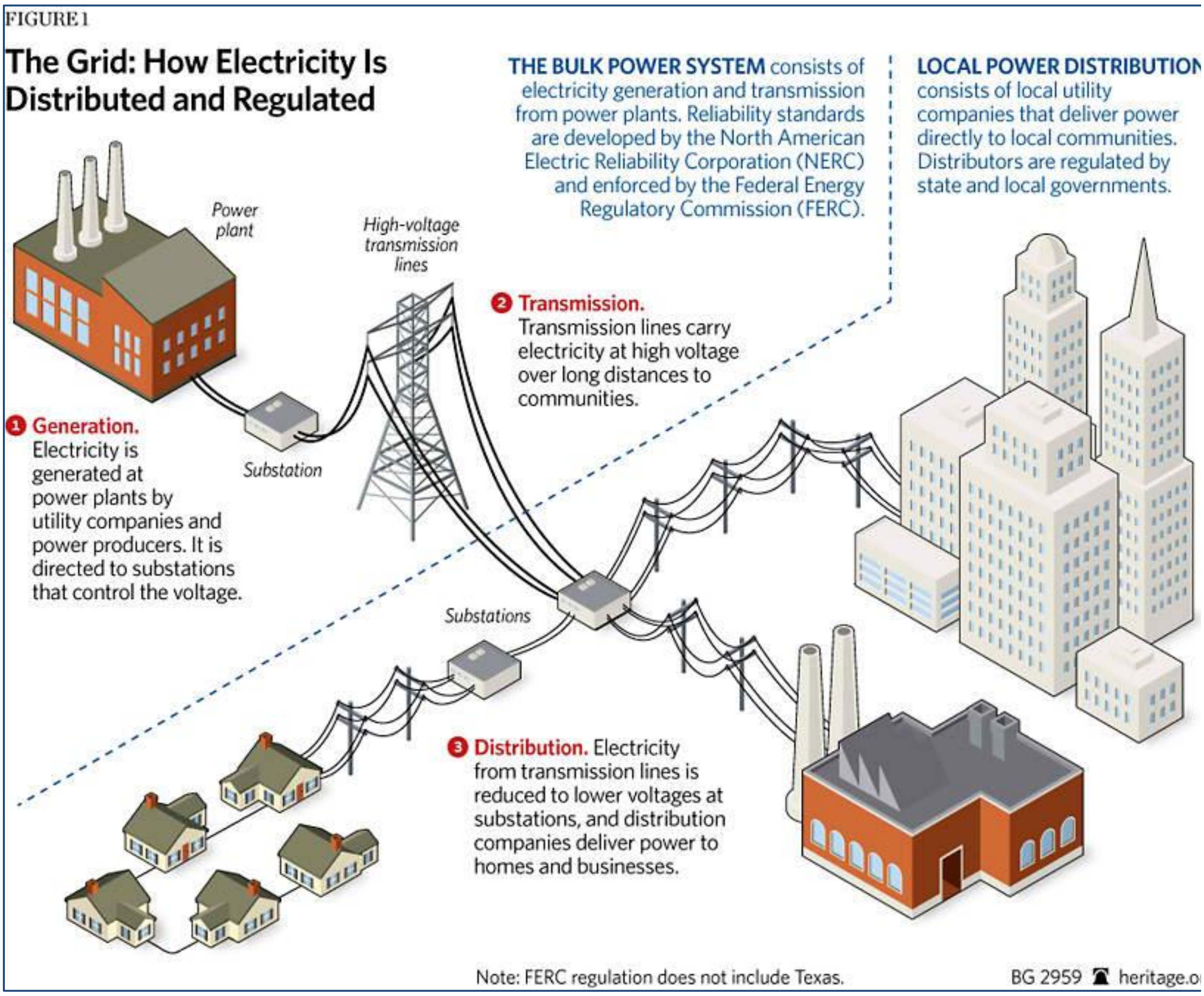
Eurandom (2012)



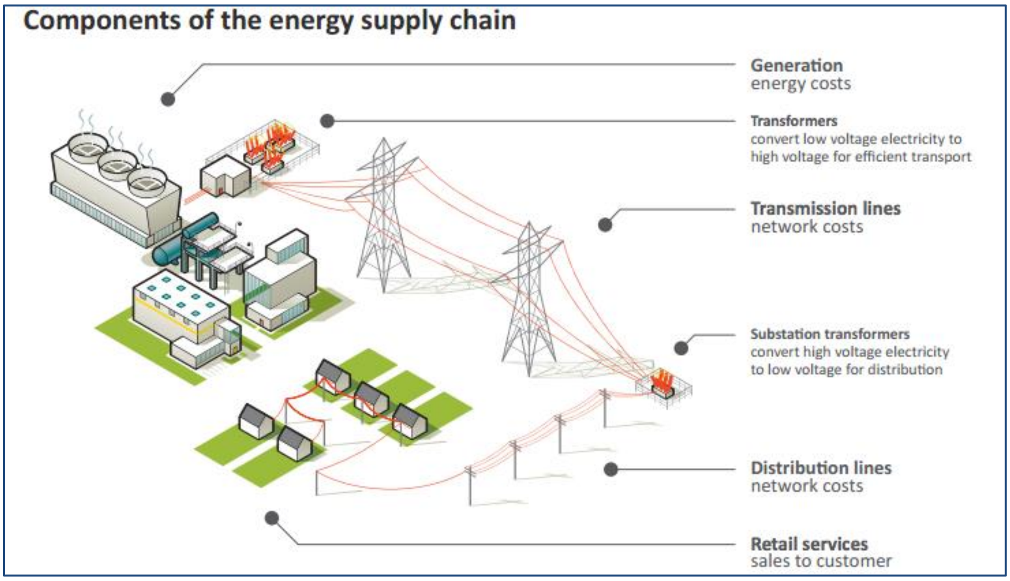
Howell, Rezgui, Hippolyte, Jayan and Li (2017)



Köktürk and Tokuç (2017)

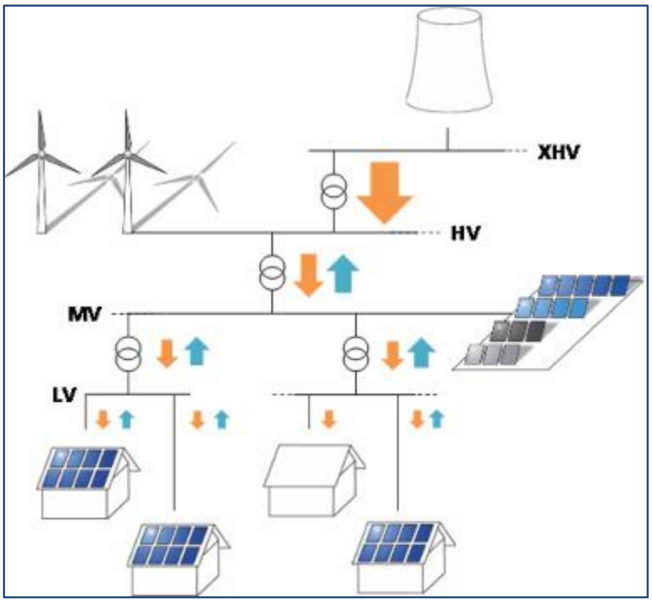


Lesser (2014)

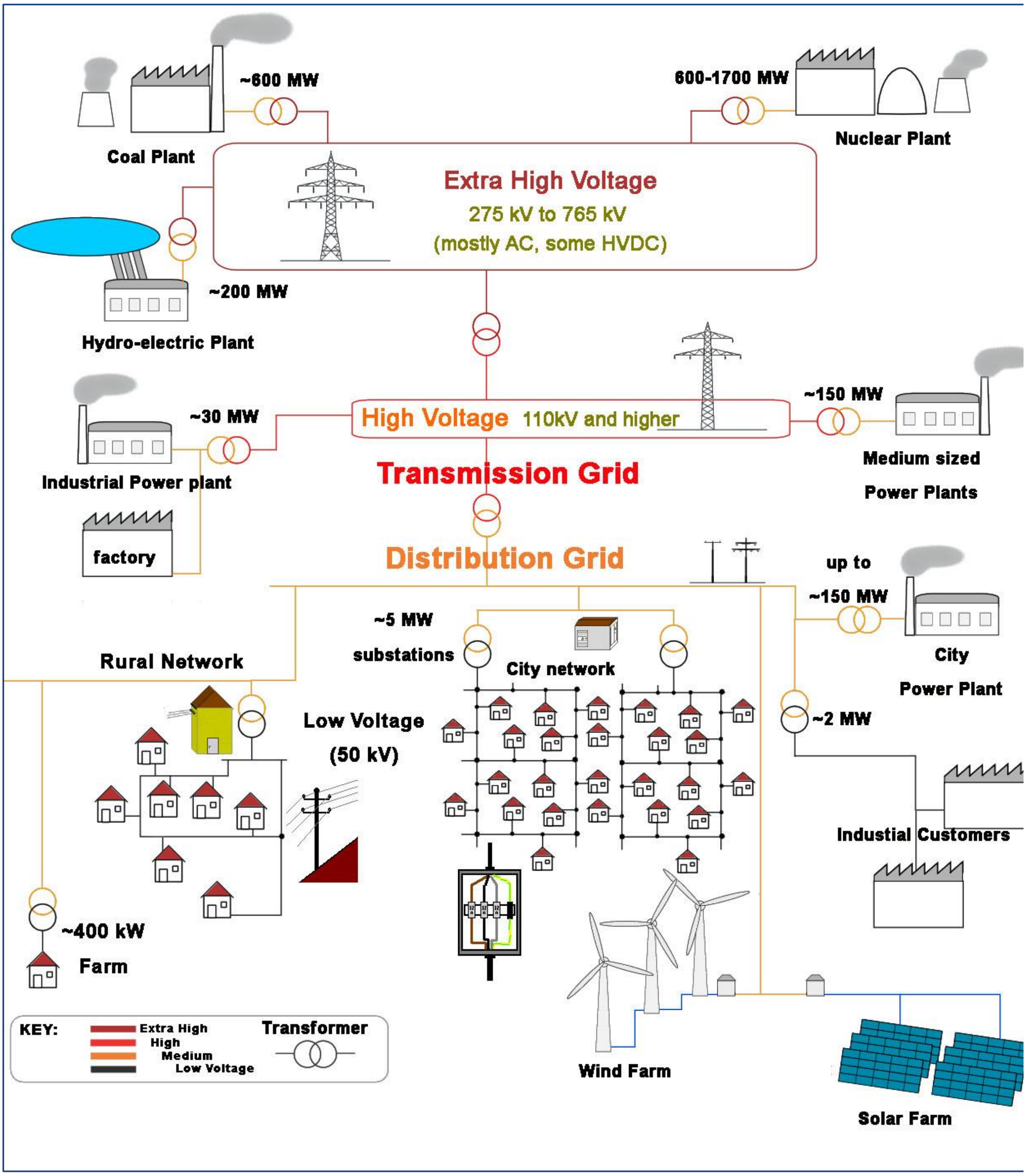


Martin (2013)

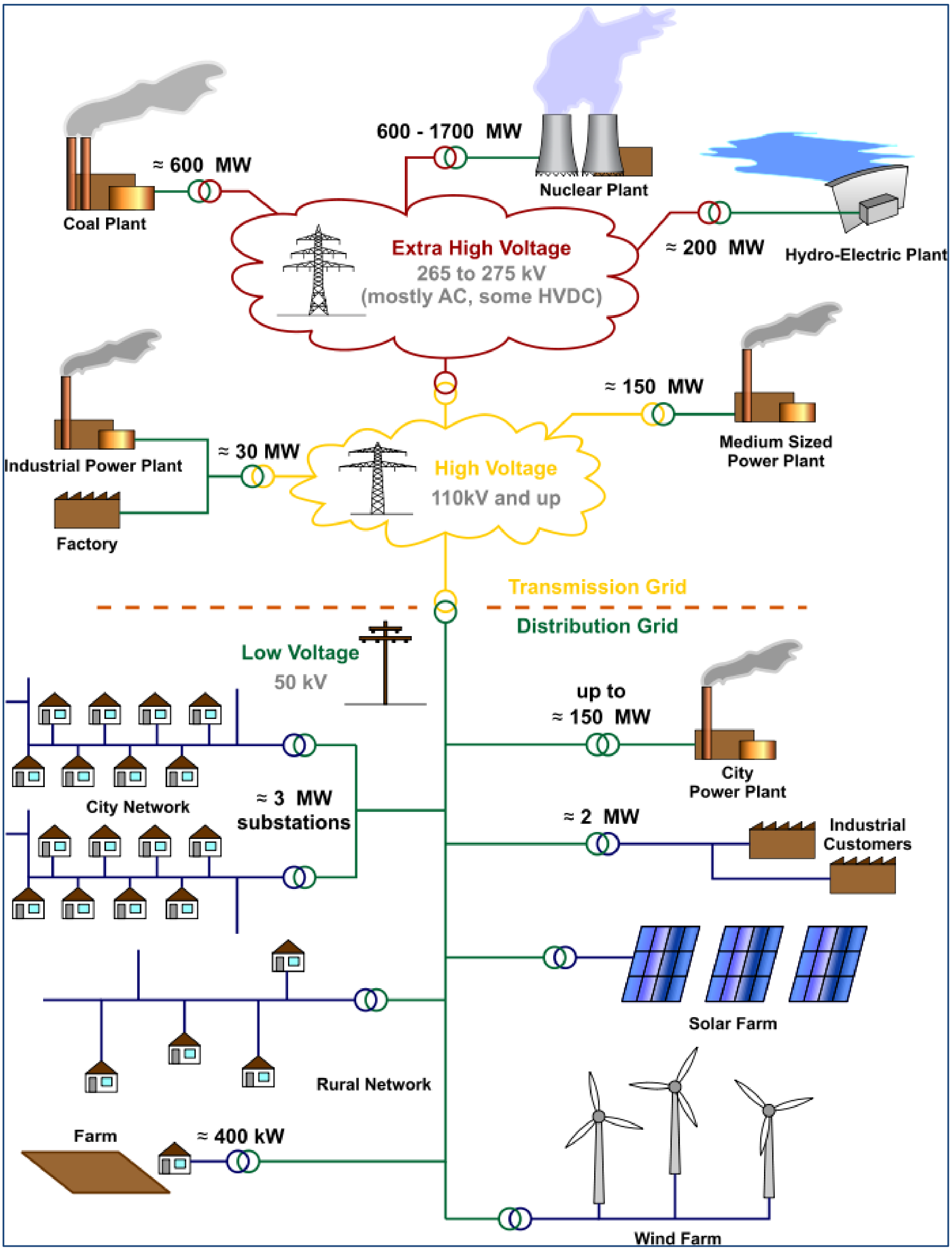
Morvaj, Knezovic, Evins and Marelli (2016)



Müller, Viernstein, Truong, Eiting, Hesse, Witzmann and Jossen (2017)



Wikimedia (2008)



Wikipedia (2017)