

Graduation report 'Smart grids in Eindhoven: an exploration'  
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## Preface

This report was written in the context of a graduation project for the master Construction Management and Urban development. During the preparation for this graduation project we explored the field of study for KENWIB. One of the subjects that kept presenting in discussions about sustainable development was smart grids. The complexity and potential of smart grids interested me. Given the chance I gladly volunteered to carry out my research project at Endinet.

Without any previous experience in the electricity sector the project proved to be a challenge. The incredible speed at which developments in the field of smart grids take place and the multidisciplinary characteristics of the process made this project a constant rollercoaster of learning experiences. The knowledge and experience of my supervisors at Endinet made a significant contribution to the project getting off to a good start.

I wish to take this opportunity to thank people who have made contributions to this project. First and foremost I want to thank my supervisors at Endinet, Eric van der Putten and Vincent van Hoegaerden for the support, advice and critical comments, which were greatly appreciated. I also wish to thank my TU/e supervisors, Wim Schaefer and Eric Blokhuis for their guidance and advice. I further wish to acknowledge the contributions made by Martijn Bongaerts and Eric van Loon from Liander and Frans Simons from Endinet. I'm grateful they allowed me to benefit from their expertise and experience. I finally wish to thank my colleagues of the asset management department of Endinet for the welcoming and inspirational environment in which I was allowed to carry out this project.

Bart Brouwers  
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## List of abbreviations

AD	Active Demand
CBS	Statistics Netherlands (Centraal Bureau voor de Statistiek)
CEER	Council of European Energy Regulators
CHP	Combined heat and power
CPB	Netherlands Bureau for Economic Policy Analysis (Centraal Planbureau)
CoEC	Commission of the European Communities
DG	Distributed Generation
DH	District Heating
DNO	Distribution Network Operator
EC	Energy Chamber
ECN	Energy Research Centre of the Netherlands
EDSN	Energy Data Services Nederland
ERGEG	European Regulators' Group for Electricity and Gas
EV	Electric Vehicles
GE	Global Economy (WLO scenario)
HP	Heat Pump
HV	High Voltage
HVDC	High Voltage Direct Current
IEC	International Electro technical Commission
KENWIB	Knowledge cluster Energy Neutral Living In Brainport
LV	Low Voltage
MLP	Multi level perspective
MV	Medium Voltage
NBNL	Netbeheer Nederland
NMa	Netherlands Competition Authority (Nederlandse Mededingingsautoriteit)
NO	Network Operator
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
PR	Program responsible organisation (Programma Verantwoordelijke)
WLO	Welfare, prosperity and quality of the living environment (Welvaart en Leefomgeving)





## 1 Introduction

This chapter will introduce this graduation project 'smart grids' of which the report is currently in front of you. It will address the reasons to start the project, the project goals, research questions, project design and is concluded by a reading guide.

Both Endinet and the KENWIB are in the early stages of exploring this subject. Since the field is broad and the technologies and market developments involved in smart grids are multiple it is important to explore the scope of developments and identify which might be relevant for Eindhoven. For Endinet it is relevant to create an understanding of the implications these developments might have in terms of investments and network operation.

A general exploration will constitute the first phase of this project. It will entail a broad study of all aspects of smart grids. Based on the insights gained during this exploration possible implications for the expected future development of the Eindhoven electricity demand will be researched. This will be done through the development of a realistic worst-case scenario for electricity demand for Eindhoven in 2040. Using the results from this scenario an estimate of the investments needed in the network to maintain operational quality at the current level under the 2040 scenario loads will be drawn up.

### 1.1 Problem statement

This section clarifies the context in which the project plan was formulated. Understanding the context is helpful in understanding how the goals and questions came to be.

It is to be expected that the energy sector will undergo some fundamental changes in the near future. These might include electric cars, heat distribution networks, decentralised generators, sustainable intermittent generators and 'smart' technology. International agreements on sustainability as well as economic and political considerations will help these changes to come about. Network operators like Endinet are at the core of these changes. What these changes entail, what they could mean for Eindhoven and the implications it could have for Endinet are as yet unknown.

There are two reasons why it would be advisable for the network operators who are an important stakeholder to become more actively involved in the energy transition. In order to be able to facilitate a smooth transition they need a definition of what requirements will emerge and sufficient time to start developing the network to be able to deliver services and capacity by the time they are required. The second reason is that it is expected that reforming the entire energy system is much more efficient than reforming the parts individually. An integrated system approach would allow for a more sustainable and efficient energy system against equal economic and social costs. (Svendsen, 2010)

In recent years sustainable policies have been focussed on stimulating developments in generation from renewable resources and reducing energy consumption. There has been little attention in sustainable policy for the energy networks or the energy system as a whole. The position and potential to contribute of the networks has thus far not been the focus in sustainability policy. There are numerous initiatives to alter the current system and develop parts of the future sustainable energy market. These initiatives all have their effects on the services needed from the energy networks. So far these effects have not been part of

the considerations being made in deciding what sustainable solutions to choose. These developments “randomly” affecting the requirements of the networks are a great concern to the network operators who need to facilitate future service requirements.

Energy network components may have a lifespan ranging up to and beyond 50 years. Changing the network to facilitate changes in the market requires investments, takes time and may temporarily disturb network operations. Additionally construction will cause direct temporary disturbance of people’s surroundings. As yet it is unknown what changes will be required or what the associated costs might be. The impact of the changes needed might require significant additional investments and lead to higher network tariffs.

## 1.2 Goals

The project serves to provide a knowledge base and generate a basic understanding of developments in the field of ‘smart grids’. The developments in the world are multiple and there is as yet little knowledge about their potential relevance to the Eindhoven region. The project serves to broaden the planning horizon of Endinet’s asset management by generating insight into future requirements. This will allow for more economical and sustainable investment decisions. Since most installed network components are expected to outlive the current planning horizon it is beneficial to expand this horizon, preferably to span the entire life expectancy of the component installed.

*The first goal is to generate insight into the future requirements of the electricity network in Eindhoven. The ability to consider the entire lifespan of components will allow for more efficient and more economical and sustainable choices.*

Additionally to serving the first goal the worst case-scenario and subsequent cost estimate will serve as a reason and means to take part in the discussion about an integrated energy system of future Eindhoven. It would be beneficial to the process of achieving ‘Eindhoven energy neutral by 2045’ if there were to be a societal discussion about the future of energy supply and use in Eindhoven. This discussion should focus on achieving an integrated energy strategy. This strategy should incorporate the current vision of reduced consumption and sustainable generation within the city. Endinet wishes to contribute to this discussion by supplying its knowledge and experience in running the current energy networks. In this role it is paramount that there is a familiarity with current vision and policy, the associated scenarios for future use of energy systems and developments in all aspects of the field of ‘smart grids’.

Developing a worst-case scenario and evaluating its associated costs should result in an estimation of investments that would be needed to sustain the current network in this worst-case scenario.

The results should provide the reason and means to initiate open discussion with other stakeholders with the intent to develop an integral energy system which will optimally and efficiently allow the goals of ‘Eindhoven energy neutral 2045’ to be achieved.

*The second goal is to explore the developments in the field of smart grids and generate insight into the potential consequences for stakeholders in Eindhoven, in order to initiate and stimulate an open multilateral discussion about developing the future energy system of Eindhoven.*

### 1.3 Research questions

Research question 1:

*What aspects and developments of energy networks are described by the term 'smart grids', what are the current developments in this field and what future developments might be expected?*

Research question 2:

*What would be a worst case scenario for the electricity consumption and expected load for Eindhoven's electricity distribution grid by the year 2040?*

Research question 3:

*In a worst case scenario, what will be the investment needed to meet the requirements for Eindhoven's electricity distribution grid by means of conventional technologies and methods?*

### 1.4 Project design

The first stage of this project comprises an exploratory study of smart grids and new developments in this field. This exploration is broadly oriented and does not exclude developments based on their usefulness in the Dutch context. In-depth engineering aspects are not an integral part of this study.

During this part of the project the current status of smart grid development is explored. In order to predict the transition path towards smart grids and the current sector, its stakeholders, organization and technical status are described and subsequently analyzed using Multi Level Perspective (MLP) as a framework. MLP is briefly introduced in subsection 1.4.1.

The second part of this study will investigate the future challenges faced by networks and their consequences when faced without the aid of smart technology. Based on the results and insights gained in the exploratory study a realistic worst-case scenario for Eindhoven is developed. To generate realistic scenarios it is paramount that there is accurate data concerning the current electricity consumption and network loads. This data needs to be extrapolated taking into account all factors influencing future use. Further assumptions include the choice of exchangeable energy carriers for different purposes. Other factors that influence the outcome of a scenario include the energy delivery model; demographic changes; economic growth etc.

There are two factors that are important to future grid development. These are peak loads and decentralised generation capacity. Given the importance of peak capacity to dimensioning the grid the scenario needs to predict the future load profile. The amount and load profile of decentralized generation is also important to grid design. Apart from capacity issues the presence of generation in the distribution grid changes network designs and will thus influence requirements and associated costs.

The final step is estimation of the investments needed in the electricity grid in Eindhoven to cope with the scenario loads. This estimation is generated using indicator numbers on network redundancy and component prices.

### 1.4.1 Multi Level Perspective

This section will introduce the Multi-level perspective on technological transition that is used as a framework to structure the analysis of the electricity sector. It is important to introduce MLP as its terminology is used throughout the second chapter. MLP is a dynamic way of looking at the process of technological transition rather than looking at just its end state. It factors in technical as well as social and economic aspects of the process. MLP looks at technological transitions at three analytical levels.

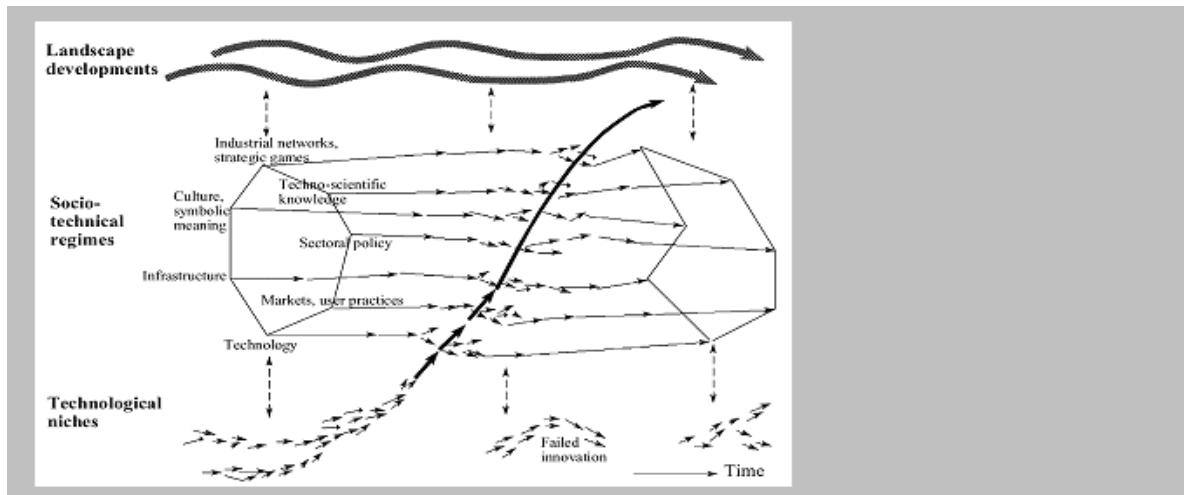


Figure 1: Dynamic multi-level perspective on technological change (Geels, 2002)

The main level is the level of socio-technical regimes. This level includes the current state of technologies and social 'rules' that form a dynamically stable situation. The regime remains stable through continuous small adjustments that come about to compensate for tensions and misalignments. These adjustments come about due to stabilizing factors that include cognitive routines; contracts, regulations, and standards; sunk investments and institutional arrangements. At this level it is not possible to explain radical change to regimes. In order to explain this the 'niche' and 'landscape' levels were introduced. (Pierick, 2009)

The socio technical landscape form the surroundings in which a socio-technical regime and a number of niches might exist. The players in the regime cannot or only slightly influence changes at the landscape level. Though changes at the regime level do not strictly dictate regime actor decisions they do influence them. Pressure from certain landscape changes can make decisions on regime level easier or more difficult.

The Niche level is the micro level in which radical changes emerge. Technical and market niches find a breeding ground at this level. They can exist and develop protected from the dominant regime by the believe of the actors involved in that niche development.

Though niche level developments are a prerequisite for transitions of the regime they are not always a sufficient condition to see the transition through. The best chance for a transition to take place is when niche developments coincide with landscape pressures pushing the regime. At this point smart grids don't yet exist. Assuming that all levels are favorable the end state of the regime level after transition should comprise a smart grid.

## 1.5 Reading guide

This section provides an overview of the project and report structure. It shows what information can be found in what part of the report, what research questions it relates to and what the relation to other chapters is. For some of the sections the nature of the information and for whom the information might be interesting is described.

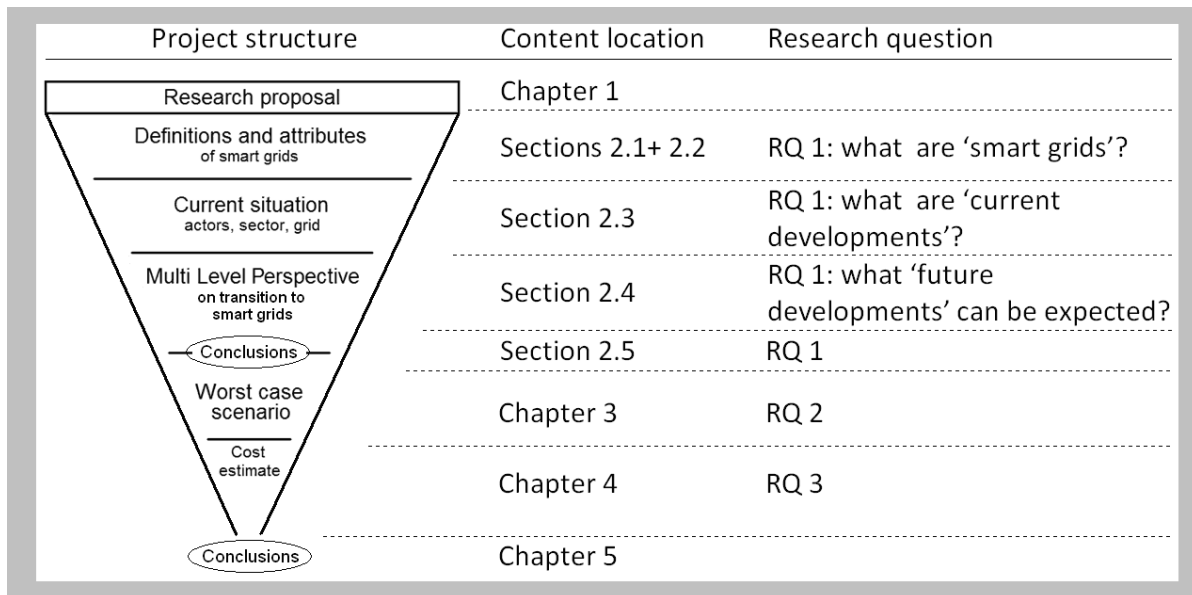


Figure 2: Reading guide

Section 2.1 and 2.2 describe and summarize the multiple definitions and attributes of smart grids as they appear in the reports and literature.

Section 2.3 is a descriptive section that aims to introduce the electricity sector. It may be of little interest to people that are already familiar with the sector.

Section 2.4 contains an analysis of the data presented in section 2.3 using MLP as a framework. This section describes the arguments used to predict a likely transition path and resulting smart grid typology.

Section 2.5 presents the conclusions from all previous sections and as such presents the answer to research question 1.

Chapter 3 presents the worst case scenario and extensively underpins the assumptions made to come to that scenario. Chapter 3 answers research question 2. Chapter three might be of particular interest to persons involved in network operation.

Chapter 4 answers research question 3. This chapter generates a result that is of interest to all stakeholders in the Energy system in Eindhoven.

Chapter 5 summarizes all results and formulates conclusions and recommendations. I would advice every reader to take the time to read this chapter.



## 2 Exploration of the term ‘smart grids’

This chapter will report the findings of a exploratory investigation into smart grids. The exploration was of a broad nature, the only aspects excluded are in depth engineering aspects.

It was apparent that to understand and predict the direction the development of smart grids will take it is vital to understand what social and economical factors influence this development. Therefore the investigation focused on these aspects and the development process rather than just the implementation and operational aspects of smart grids. In order to organize the exploratory phase of this research project, the development of smart grids was considered using the Dynamic Multi Level Perspective (MLP) model for transition processes by Geels (2002). MLP is not an analytical tool and can't predict developments but it can be used to structure the analysis of technical transition processes. (Pierick, 2009)

Section 2.1 describes the multiple definitions for smart grids that are in use today. It also identifies the definition of a smart grid as it will be applied in this research project.

Section 2.2 introduce the attributes and functionalities currently associated with smart grids. Section 2.3 describes the current electricity sector including stakeholders, the sector's organization, technical aspects and existing infrastructure.

Section 2.4 analyses the data from section 2.3 and presents arguments on what would be a logical transition pathway. This section builds on the MLP method.

Section 2.5 will summarize and conclude the findings from this chapter. The findings will serve as input for the scenario developed in chapter 3.

### 2.1 Definitions

There are a lot of interpretations of the term smart grid. This section will introduce different definition types and definitions. Finally the choice for the ERGEG definition as the definition used throughout this project is explained.

To be able to understand the different meanings and definitions it is important to consider who is using the term and in which context it is being used. There are three types of definitions that are being used to define a ‘smart grid’. Problem based definitions are based on the textual context in which the term is being used. Standard definitions are objective, unbiased and generally applicable definition. The third and final type of definition are based on a time and location specific definition that defines the smart grid as it is applicable to the specific context. Different uses of the term smart grids are best served by different types of definitions. In an international debate and/or technical discussion a definition of the second type is most suitable since it prevents miscommunication. The third type of definition might be better suited to describe development processes since it incorporates conditions specific to the context of the development.

‘Smart Grid’ is a term that can refer to several energy grids including electricity grids. The taskforce ‘smart grids’ of Netbeheer Nederland (NBNL) has even proposed to, for the time being, use the term ‘smart energy systems’ instead. It is important to realize there is a relationship between different energy systems. Changes to the electricity grid will often influence the use of other systems like gas, heat and fossil fuels. Due to the scope of this project the definitions proposed will only consider electricity grids.

### 2.1.1 Problem based definitions

The first type of definition is often used in publications dealing with (technical) developments, often in generation and consumption. Often these are niche level developments that need the socio-technical regime to change in order to become successful. Publications about innovative technologies therefore often state that a smart grid is needed for successful full scale implementation of the innovation. Actors within the regime also use the term in this context. Even landscape pressures are sometimes translated into a need for a smart grid. The following definitions of smart grids are problem based definitions from all levels of

- Concerning new intermittent decentralised generation a 'smart grid' was often proposed to allow the grid to function as an unlimited storage facility.
- The smart grid should deliver real-time load information to maintain voltage and power quality on the grid when decentralised production becomes more significant.
- To prevent overloading grids without physically investing in new cables the smart grid should facilitate market functions to stimulate consumers to change their behaviour in a way that decreases maximum loads.
- From a sustainability perspective the smart grid is expected to stimulate consumers to be more economical. Smart technology should also allow more efficient grid operation so less energy is lost in transportation and distribution.

When the term smart grid is used in this context the definition, even when not explicitly described, can generally be summarised as: "a smart grid is a grid that is a solution to the problem or challenge described in this publication". This means there is a specific smart grid for every problem. This approach to defining smart grids results in an almost indefinite amount of definitions of the term. The concept of defining smart grids by the context in which the term is used is of little practical use to structured discussions about developing smart grids.

### 2.1.2 Standard definitions

The second approach to defining a smart grid is to objectively assess what characteristics are always or most commonly associated with it. This approach is taken by the International Electrotechnical Commission (IEC) which is the international standardization commission for electrotechnics of which NEN is a member. As the organisation responsible for developing international quality and safety standards the IEC usually gives internationally unified definitions. In 2009 the IEC circulated the following concept definition amongst its members:

*"Smart grid, intelligent grid, active grid: Electric power network that utilizes two-way communication and control-technologies, distributed computing and associated sensors, including equipment installed on the premises of network users".([www.iec.ch](http://www.iec.ch))*

This definition focuses on the characteristics of the network rather than the functionalities the network provides. The definition is clear and unambiguous. The proposed definition is also very broad. It includes most, if not all, problem based definitions of the term 'smart grids'. Though clear and unambiguous this definition is so broad that it is little help in establishing what a smart grid might actually look like.



### 2.1.3 Demarcating definitions

The third and final approach is to define a smart grid by the technical and functional specifications it is expected to perform. This should provide a relevant definition that is location, time and situation specific.

Landscape pressures and niche developments are currently influencing the European regimes. So far this has not resulted in a coherent idea of what a smart grid should be. This means that neither for the European, nor for the Dutch context there is a definition through this approach yet. Several organizations have introduced definitions that indicate certain landscape pressures and niche developments that will be of interest within their context of smart grids. The definition introduced by the European Regulators' Group for Electricity and Gas (ERGEG) is developed this way. It addresses developments at the landscape level and matches this to developments and opportunities at the regime and niche level. The definition is still broad enough to be applicable for all of Europe and does not yet fully define a smart grid. In this sense it is more of a demarcation than a definition.

***"Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."***  
(ERGEG, 2009)

In line with this type of definition the 'smart grid' taskforce from 'Netbeheer Nederland' has chosen not to define a 'smart grid' at this time. They feel there is too much uncertainty about the direction Dutch smart grid developments will take.

### 2.1.4 Project definition

Throughout this report the term 'smart grids' will refer to the definition proposed by ERGEG. This definition is the most specific definition that includes most, if not all, possible developments relevant to the Dutch context. In mentioning economic and technical efficiency, sustainability, reliability and safety it also addresses the challenges a smart grid should help to meet. On the other hand the definition does not specify what form a smart grid should take and thus reflects the uncertainty concerning the direction the development will take. This does on the other hand also create freedom for various developments.

The definition reflects the level of demarcation that applies to the term given the current state of development in the Netherlands. At this time this demarcation level is also suitable for Eindhoven since the future of the Eindhoven energy systems has not been further defined than the national systems have. Since this report aims to provide an insight into possible development of smart grids in Eindhoven this definition will suffice.

## 2.2 Functionalities attributed to 'smart grids'

Even though there is no consensus about what a smart grid should exactly be, there is a number of functionalities that are generally attributed to smart power grids. This section will describe these functionalities. It is important to have an idea of which functionalities are associated with smart grids in order to understand the scale of the changes proposed.

There is an almost endless list of possibilities and the goals set will eventually determine which functionalities will be realized.

The goals and subsequent functionalities are derived from analysing a number of sector reports on the future of (smart) grids. The publications used include recent publications by NBNL, ERGEG and the European Smartgrids Technology platform.

Most stakeholders directly involved with networks, including ERGEG and NBNL, consider smart grids solutions to apply measures that allow for increased intelligence for planning, operating and maintaining networks. Even though these three tasks in a network life span are very different the smartness starts with information. Nearly every functionality described as part of a smart grid starts with having more accurate, often real time information about network and component performance. The smartness of the network then lies in utilizing the available information to a certain goal.

Smart metering is a development that is very much associated with smart grids. Often confused with smart grids it is important to realize that smart metering in itself does not constitute a smart grid. The information provided by smart metering will be of great importance to defining and planning future grids as well as monitoring and managing them. When combined with other factors like differentiated tariffs or variable connection capacity contracts the information provided by smart meters can be used to influence what happens behind the meters. Figure 3 shows what position smart metering takes in smart grids according to ERGEG.

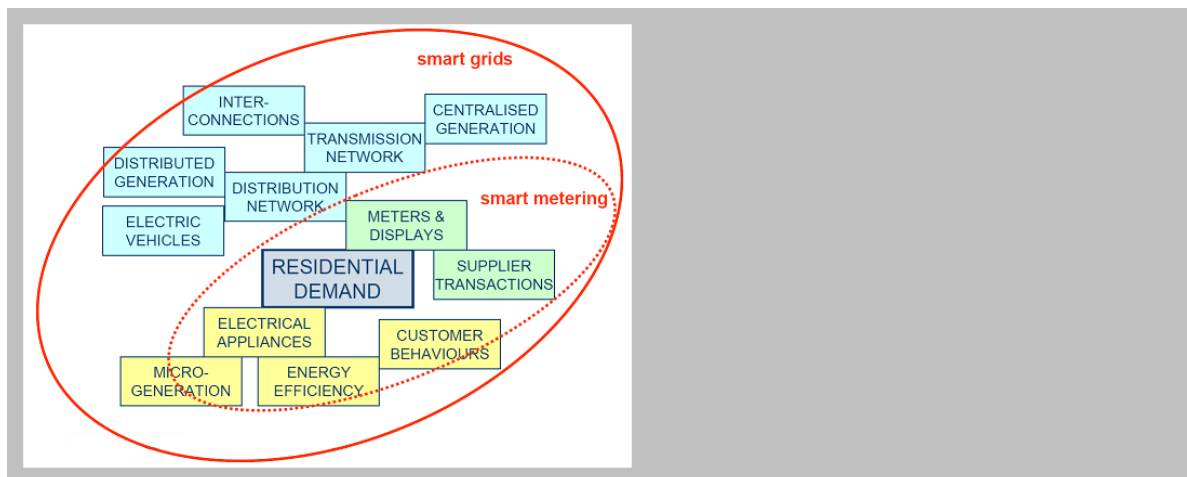


Figure 3: ERGEG elements of smart grids and smart metering (ERGEG, 2009)

The next two subsections will describe the way information and IT can be utilized and the functionalities this can add to the grid.

### 2.2.1 Grid planning

In the past grid operation was generally very one directional, utilizing central generation and distributing power via MV and LV to an inactive demand side. The grid was designed to be able to maintain operation in a maximum demand condition and it was assumed that all other operating conditions would be within this capacity. In order to deal with increasing DG, intermittent generation and international trading more complex models for grid planning need to be used. Due to DG and intermittent generation it is very likely that individual network sections will experience maximum capacity requirements on different times than just at maximum demand.

Detailed information about past and present use allow for more accurate modelling. Increased real time control of grid use results in decreased uncertainty about the capacity that grids need to be designed to. A system including active generation and demand management would thus allow for grids to be planned with less redundancy built into them.

The information, more accurate modelling and increased ability to control grid operation will allow for better cost-benefit analysis (CBA). While at the local level the grid is expected to remain facilitating demand at any cost, CBA might become very important in planning transport and (international) transmission networks.

### 2.2.2 Grid operation

There are numerous functionalities that smart grids will provide that current grids cannot or not fully offer. To the network operator it provides a wide range of advantages.

They include:

- Reduced peak demand (active demand)
- More accurate balancing of generation and use (virtual power plants)
- Reduced network losses
- Increased coordination of cross border inter connection
- More accurate monitoring of grid performance
- Automated corrective actions after failure (self healing)
- Automated preventive actions

Real time information about demand allows for active demand management. This means that some sort of control signal is send to users which have the ability to respond to it in a way that might contribute to peak shaving, balancing, maintaining grid stability or reducing network losses. The signal could be related to all sorts of things like cost, capacity, CO<sub>2</sub> emission.

Active demand aides in balancing generation and demand. Active generation control and electricity and/or energy storage can contribute as well. When new technologies like heat storage, CHP or even batteries become available in the system having them react to the same signals that influence demand will make balancing easier. Increased control and more efficient planning of inter-connection capacity might contribute as well.

Having the real-time information about generation and demand, a way of influencing them, storage capacity and possibly real-time information about grid component performance (thermal monitoring) will allow for measures to reduce network losses.

Overall the information available on generation and demand as well as load flows at nodes and thermal monitoring will allow more accurate monitoring of grid performance than ever before. Combined with remote switching there is an increased chance preventive action can be taken. In case of contingency faster and more effective corrective measures will be possible. (ERGEG, 2009; ETP Smartgrids, 2006)

## 2.3 Description of the current electricity sector

This section will describe all aspects of the current socio-technical regime in the Dutch electricity sector. The aspects that are considered are: 'stakeholders'; 'the organisation of the electricity sector' and 'grid technology'. The aspects considered will be generally

described. The information presented will subsequently serve to analyze the forces currently influencing potential future developments. The texts also aim to provide a general insight into all aspects of the electricity sector and are therefore broad and generally descriptive. For each of these aspects the current situation is described. Section 2.4 will subsequently present a pragmatic analysis of the effects these aspects have on the technological transition towards smart electricity grids using MLP as a basic framework.

### **2.3.1 Stakeholders**

The electricity network has a lot of stakeholders. These often have conflicting interests and therefore their position on smart grids might be different. This subsection describes the main stakeholders and their general attitude towards the sector and smart grids in particular. (ETP Smartgrids, 2006; Electriciteitswet 1998)

#### **2.3.1.1 Consumers**

Users were always a very passive stakeholder in the electricity sector. Their needs included quality and safety of service as well as value for money from both the network and the supplier. On these aspects the Dutch electricity networks are amongst the best in the world. (CEER, 2008) The roll of the user is changing into a more active one. Future needs will include the freedom to choose suppliers, real time tariffs, value added services and the ability to sell back surplus generation to the network.

Most users are small users and see the network as the public utility it always was. Value for money is not yet a individualised consideration since the government still regulates the sector and choice of network supplier and service level is limited.

#### **2.3.1.2 Network operators**

So far the role of the network operator (NO) is to fulfil the market parties expectations optimizing to the aspects of reliability, affordability and security set in Dutch regulation. The current responsibility to affordably provide sufficient capacity remains unchanged. Smart solutions that give the grid a more active role in the electricity system will allow better performance on efficiency, safety and sustainability. Whether it is the grid operators or the regulator that fills this more active role is a question to be answered. NO's as well as their representative bodies have expressed the willingness to take part in developments and consider the position that NO's should have in future smart energy systems.

#### **2.3.1.3 Government**

Governments will have to prepare new legislation and guide regulation to reach new and apparently contradictory goals. For example, economic growth and free market might go well together but will certainly be harmful to the interest of sustainability. Such contradictions are apparent between many interests in the sector.

Governments will have to weigh the different interests and provide legislation for the sector. This includes legislation on the boundaries for the liberalised parts of the market and stimulation of desirable development thereof. For the networks the regulation will have to be changed to accommodate the transition towards the new situation. Regulators will need to be given a new or adapted set of interests and priorities to implement through regulation.

#### **2.3.1.4 Production and supply companies**

This is a very broad category of stakeholders. Most traditional production companies also trade electricity and sell to users. There are however companies that only trade wholesale and an ever increasing number of companies that trade electricity and sell to users. The

interest this group has in smart grids is also very diverse. Reductions in energy consumption and an increase of micro generation by private individuals are a clear threat to the position and turnover of the traditional production and supply companies. On the other hand technological developments as well as market developments offer chances for new services. The dynamism in the sector offers chances to smaller players and promotes competition amongst parties. This implies that developments might hurt this group as a whole but will offer individual companies chances to grow and develop new business.

### **2.3.2 The sector's structure**

The electricity sector is a sector in which societal interests meet huge financial interests. Internationally there is a lot of competition for energy. Nationally the sector is liberalized but some general interests are still protected by public ownership and regulation. This subsection introduces the structure and organizational aspects of the current electricity sector.

#### **2.3.2.1 Regulation and policies**

The Network company has the responsibility to: (Elektriciteitswet 1998, artikel 16)

- provide transport of electricity over the networks in the most efficient manner
- maintain sufficient reserve capacity for the transport of electricity
- provide third parties with connections to the network
- transport electricity on behalf of third parties
- to stimulate and improve safe use of appliances and installations that use electricity

Building on this foundation in the electricity law a system of regulation structures the sector. The current system of regulation of electricity and gas networks has been implemented at the end of the twentieth century. First experiences and several international developments have since brought on changes and refinements to the system. The last major change has been made by the 'law on independent network management' (wet onafhankelijk netbeheer) commonly known as the 'separation act' (splitsingswet) that came into power November 23<sup>rd</sup> 2006.

The separation act aims to improve affordability of energy supply by promoting competition in parts of the energy market. The liberalised parts mainly include production and supply. To do this the separation act demands that all network activities will be separated from existing energy production and supply companies and become individual publicly owned private entities. This unbundling allowed the energy market to be liberalised and encourages competition between different production and supply companies. The networks operators remain monopolists and therefore the regulatory system still applies to DNO's.

The current energy policy and subsequent regulations are centred around securing three public interests. These public interests are an affordable, clean and reliable energy supply. These interests have been the main pillars under the energy policy. The regulation of the network operators is focussed on providing the right stimuli to get energy networks to optimally contribute to securing these public interests. The Energy Chamber (EC) stated in its review of future regulation that innovation and free market competition are just means to meet these three main public interests. They are not goals in their own right. (NMa, 2009)

The interest of reliability of delivery is interpreted as reliability of transport as far as network operations is concerned. This translates in to the demand of maintaining a high quality

network with sufficient capacity to allow all market parties equal and unrestricted access to its services. All other aspects of reliability of delivery are dealt with in other parts of the energy system.

With regards to the interest of achieving a 'clean' energy supply the Energy Chamber remarks that all policy is aimed at the source of energy and the method of converting it. This public interest is served by these factors and the energy networks should only facilitate the changes that this policy brings to the energy network. The Energy Chamber does not see an active role for the networks in achieving a clean energy supply. (NMa, 2009) The current system of yard stick competition between DNO's (see subsection 2.3.2.2) actually punishes the first DNO to invest in new developments by allowing less profit in the next regulation period. This effect is called the first-mover-disadvantage and prevents Dutch DNO's from individually embarking on new and innovative developments.

#### **2.3.2.2 Markets**

The Energy Chamber of the Netherlands Competition Authority (NMa) interprets affordability in the case of network management in two ways. In liberalised parts of the market the price needs to be competitive through market processes. Network management needs to facilitate this by impartially supplying sufficient capacity to the commercial parties. (Netbeheer Nederland, 2009)

In the monopolistic parts of the market regulation is used to supply the stimuli that are absent in a monopolistic situation. It means that the network operators are allowed to make a reasonable return on investments when they appropriately and cost efficiently operate their networks. (NMa, 2009)

To provide the artificial stimulus for economic efficiency amongst DNO's, price-cap regulation with yardstick competition is in place. The allowed revenues are derived from the average DNO's costs in the previous few years accounting for a reasonable return on investment taking into account the risks DNO's bear. This system inadvertently means that a single DNO that invests in sustainable innovation will be "punished". The DNO in question will be considered less efficient than the 'competition' and as a result will be allowed less revenue. The system operators thus are faced with an incentive to postpone investments. The same goes for operational expenses including research into (sustainable) innovations. A number of DNO's strongly advised the Dutch regulator to leave investments and operational costs allocated to sustainable development and innovation out of the yardstick competition. (Netbeheer Nederland, 2009)

#### **2.3.2.3 Industrial network**

A lot of changes are happening in the energy sector in the Netherlands. A significant part of this dynamism is a result from the law on independent network management (2006). On the 22<sup>nd</sup> of June 2010 the Court of Justice in The Hague ruled that there were insufficient grounds to justify the infringement on the freedom of capital that the separation act posed. Delta, Eneco and Essent had taken legal actions against the separation act to evade mandatory separation. The State has appealed this decision and thus the future of separation act is still unclear. Assuming the separation act holds up the current developments will continue. These developments are different for different players in the sector.

Production companies are private companies and are part of a European Energy market. The players on this market are generally bigger than the individual Dutch Energy companies. They have therefore been considering competitive strength. Nuon and Essent investigated the possibilities for a merger but this failed. Recently Nuon Energy has been bought by the Swedish company Vattenfall and Essent was sold to the German RWE. The biggest producers in the Netherlands are now all owned by foreign companies. Only Delta, being a mixed utility company, is still under Dutch ownership.

The transfer and distribution networks are run by the network operators. In the Netherlands these network operators are publicly owned private entities. They are concessionaires that are monopolists in their respective concessions. Being fully owned by public organisations the network provides impartial services to commercial parties operating in the electricity market. The network companies operate both electricity and gas networks. Since the market can't control monopolists a system of regulations is used as one of the tools to ensure that the network operators maintain quality and capacity in an efficient and responsible way. This regulatory system complements and strengthens the instruments of encouragement and ownership. (Commissie Kist, 2008)

There is a lot of activity amongst network operators. To remain strong and dynamic in a changing environment the DCO's are consolidating their positions. In this process a number of mergers and buyouts have happened. It is predicted by some that eventually only 4 or 5 (big) network operators will remain in the Netherlands. Others suggest that eventually there will only be a single network operator remaining. In this process Endinet has recently been sold and is part of Alliander since July 1<sup>st</sup> 2010.

### **2.3.3 The electricity grid**

This subsection introduces the current electricity grid, the technology behind it and addresses its ability to cope with change.

#### **2.3.3.1 Technology**

This subsection will review the current technologies that shape the current electricity networks. Technological details are not a part of this exploration so the technologies will only be reviewed on their system implications. For understanding a short introduction will be given into the basics of electricity and electricity networks.

The technologies in use today shape the current system and the specifications to which it operates. New technological developments in the network will create new possibilities and enable new functionalities. Developments in generation and use will change the demand for network capacity and functionalities.

##### **2.3.3.1.1 Introduction electricity networks**

The European electricity system is run on 3 phase alternating current electric power. This system utilises three conductors carrying alternating currents. These have the same frequency but are delayed relative to each other by  $+1/3^{\text{rd}}$  or  $-1/3^{\text{rd}}$  of a cycle. (Figure 4)

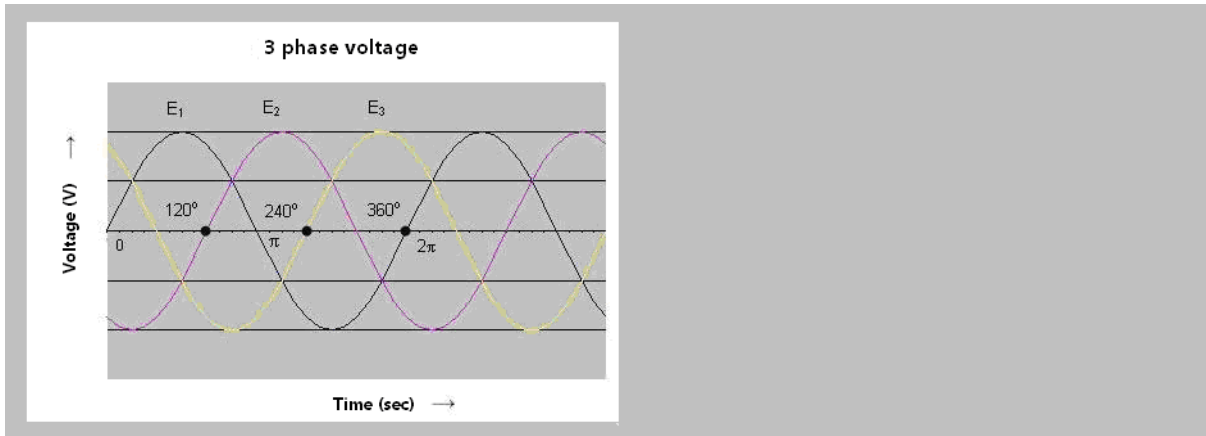


Figure 4: 3-phase voltage cycle

The choice for alternating current is generally explained by the ease by which it can be transformed to other voltages. This allows for transport at high voltage reducing transport losses. After generation electricity is typically transformed into 380kV for national transport lines and transformed down through the 150kV and 50 kV networks until it reaches the local medium voltage networks which operate at 10kV. This network delivers to the transformer stations that feed the local 400 V network that delivers the electricity to the general household consumer.

The choice for three phase as opposed to single phase can be explained by three advantages that exhibit itself with multi phase currents with three or more phases.

- The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to eliminate or reduce the size of the neutral conductor; all the phase conductors carry the same current and so can be the same size, for a balanced load.
- Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- Three-phase systems can produce a magnetic field that rotates in a specified direction, which simplifies the design of electric motors.

Three phase generators and motors usually comprise 3 identical sets of coils that are positioned at  $120^\circ$  towards each other. In the Netherlands they are connected to a single neutral connection. This connection type is generally referred to as star connection. The electric potential difference between any single phase connection ( $U_{\text{phase}}$ ) and the neutral is  $1/\sqrt{3}$  the difference between any of the two phase connections ( $U_{\text{line}}$ ). Usually electricity connections in the Netherlands are 400V line voltage. This means that in a triangular connection the difference between any two of the connection points is 400V. The associated phase voltage from the same three phase connection is 230 V ( $400 \text{ V} = \sqrt{3} * 230 \text{ V}$ ). This is achieved by connecting any of the three phases to a neutral using a star connection.

(Figure 5)



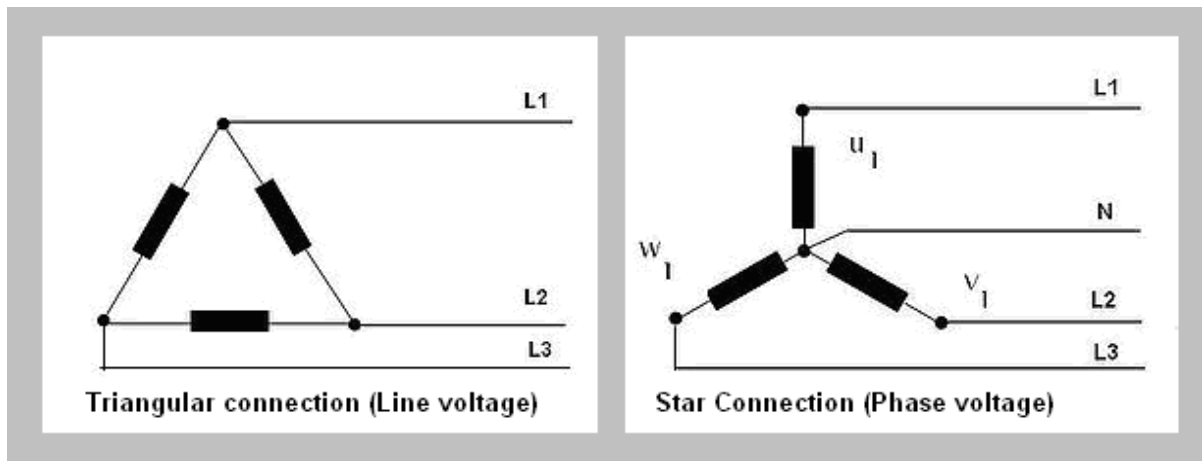


Figure 5: 3-phase connection types

The distribution grid in Eindhoven was laid out to comply with all existing regulations. The design is typified by the fact that the local MV traces are loops instead of radial cables. The LV network is a mesh network within each loop. This layout has the advantage that whenever a disturbance occurs the power can be rerouted from another transformer. This means that the down time in Eindhoven is generally shorter than in radial grids for the same occurring problem. The entire network has been laid out using the n-1 principle. This means that there is always a redundancy in the design which allows for a cable or transformer to be switched off for maintenance or repair without turning off the rest of the grid.

#### 2.3.3.1.2 Network technology

As most electricity networks in Europe the Dutch network is a 'conventional' electricity grid. It mainly consists of copper, aluminium and iron. The electricity system is dominated by large controllable generators. The centralised production in the Netherlands is based on numerous coal and gas power plants and a single nuclear facility. In recent years a significant number of decentralised generators has been added to the HV and MV system. They now comprise up to 30% of the total production. A significant share of the decentralised production is still owned by the electricity companies producing in joint ventures with several industries. (Compendium voor de leefomgeving, 2010)

The network has very little storage capacity. In the past production was constant and surplus production was lost. Balancing generation and electricity use is now done by controlling production at the central generation facilities. Not so much a technology as a management system, balancing is at the core of the current network operation. Balancing is done by the programme responsible parties (PR's). Every day projections are made concerning the total of electrical power needed the next day. This projection is based on the standard profiles and client data supplied by the PR's. The PR's thus predict the need of the connections associated with them. Based on these projections the PR's make an agreement on the total volume to be produced and who is going to produce it. A system of (re-)calculations is then used to determine the difference between the predictions and the actual use. This system will be introduced in subsection 3.3.4.

Today there is a steadily increasing number of users that generate electricity at MV and LV levels. They are entitled to deliver their surplus electricity into the network. (Electriciteitswet 1998) The new facilities include non-controllable generators like wind and PV and semi-controllable generators like CHP installations. The latter technology is controllable but other

factors than the state of the electricity balance, in this case the need for heat, are used to determine whether the facility generates electricity or not. The uncertainty about decentralised production and the unpredictability of intermittent generation makes balancing production and consumption increasingly difficult.

#### 2.3.3.1.3 Generation technology

As stated in the previous subsection electricity was traditionally generated in a limited number of centralised facilities. More importantly the generation facilities were owned and operated by a limited number of producers. Nowadays the search for more sustainable resources has led to a number of alternative generation technologies being introduced. In some instances the generator utilizes the same technology on a different scale or is powered by a different energy source. CHP and wind generators are examples of this. Other generation methods like PV generate electricity using an entirely different technology.

Decentralised generation from a network perspective can be defined as generation that: (Jenkins, 2001)

- is not centrally planned
- that is not centrally operated
- is mostly connected to distribution networks
- is smaller than 50-100 MW

Possible effects of the introduction of decentralised generation as identified by Endinet are: (Endinet, 2009)

- Voltage change
- Increase in short circuit current
- Power quality
- Electro technical securities
- Stability
- Maintenance
- Network losses decrease

In 2004 sustainable electricity contributed 4% to the national electricity production. In 2009 this has grown 9% to the total national electricity production. (CBS, 2009) It is expected this percentage will continue to increase due to policy aimed at achieving the EU goal for the national energy production to be 20% sustainable by 2020. (CoEC, 2008) About 60% of all sustainable generators being introduced is decentralised. Given the attention for sustainability it is to be expected that the number of decentralised generators will continue to grow.

#### 2.3.3.2 Infrastructure

Existing electricity supply systems are dominated by large, controllable generators connected to an inelastic demand side by transmission and distribution networks. (ERGEG, 2009)

The Dutch national transfer network is owned and operated by TenneT. High voltage, high capacity circuits are traditionally used for cross country bulk transfer of electricity. Recently a number of High Voltage Direct Current (HVDC) connections have been realised or planned connecting the Dutch network to England, Norway and Denmark. International connections are used to solve national surplus or shortages. Tennet delivers the electricity from central

generation facilities to several regional network operators. These operators distribute it through medium and low voltage systems to the end user. LV is the voltage level at which most end users are connected. Most households are connected to 230 V phase voltage from the 400 V line voltage cable.

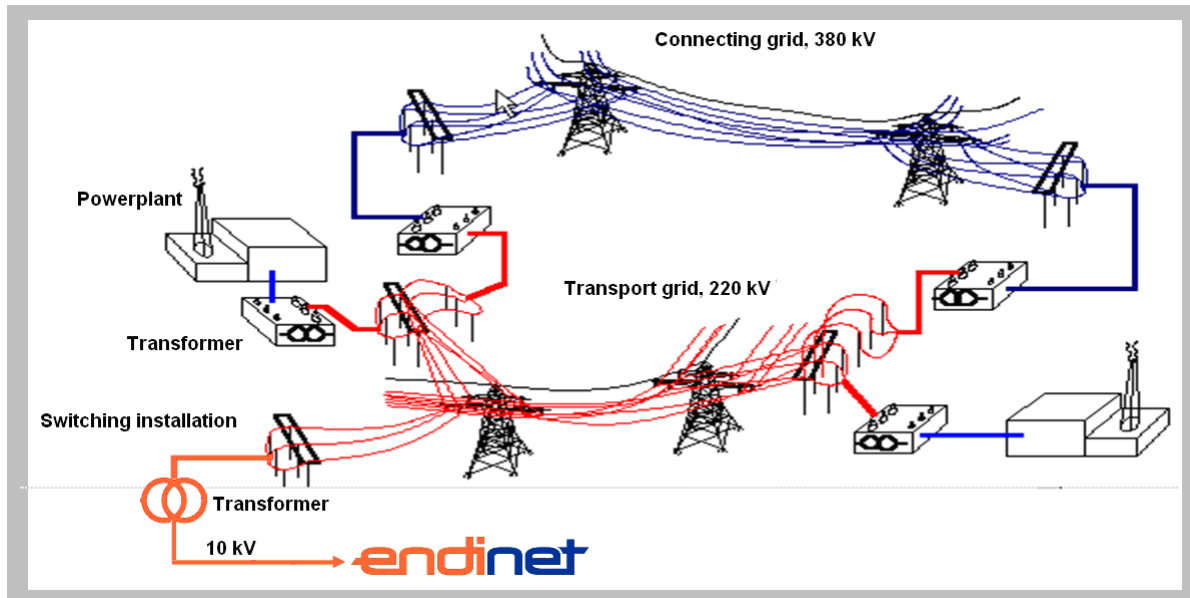


Figure 6: Schematic Dutch electricity network

The existing infrastructure represents a huge financial value. This was shown in the process leading up to the unbundling of the energy companies. The public owners of the networks were then allowed to sell 49% of their networks to private parties. 'Financieel adviesbureau Sequoia' estimated the economic value of the electricity and gas networks in the Netherlands to be between 24 and 30 billion Euro's. The replacement value of the networks may even be many times higher.

The energy networks are mostly integrated in the built environment. The majority of the network components are cables that lie buried in urban areas. To replace or add components extensive construction activities will be needed in the public domain. Large scale alterations to the existing infrastructure will therefore result in considerable inconvenience to society.

#### 2.3.3.2.1 Existing infrastructure Eindhoven

In Eindhoven the distribution network is operated by Endinet. The local network consists of 3 stations that are supplied by Enexis. From these station 10 kV is distributed through 9 main distribution stations, through 30 neighbourhood distribution stations to about 1100 electricity substations where it is converted into 400 V. From these substations the electricity is distributed to over 105,000 LV client connections in Eindhoven. There are about 570 clients connected directly to the MV network. (Simons, 2009)

The network in Eindhoven is laid out in MV rings that feed the transformer stations. Within these rings the LV network is a mesh. The entire system is dimensioned to a 'n-1' specification. This means that any cable may break down or be switched off without delivery to the clients being influenced. The same goes for transformer stations on the MV rings. Any of these may be switched off without delivery being interrupted. A great advantage of MV

rings with a LV mesh is that disturbances can quickly be bypassed reducing the downtime of the network. Generally the rings are switched open at one end of the cable. In case of a failure in the MV loop the problem can be isolated and the ring can be opened from both sides, again providing power to all transformer stations.

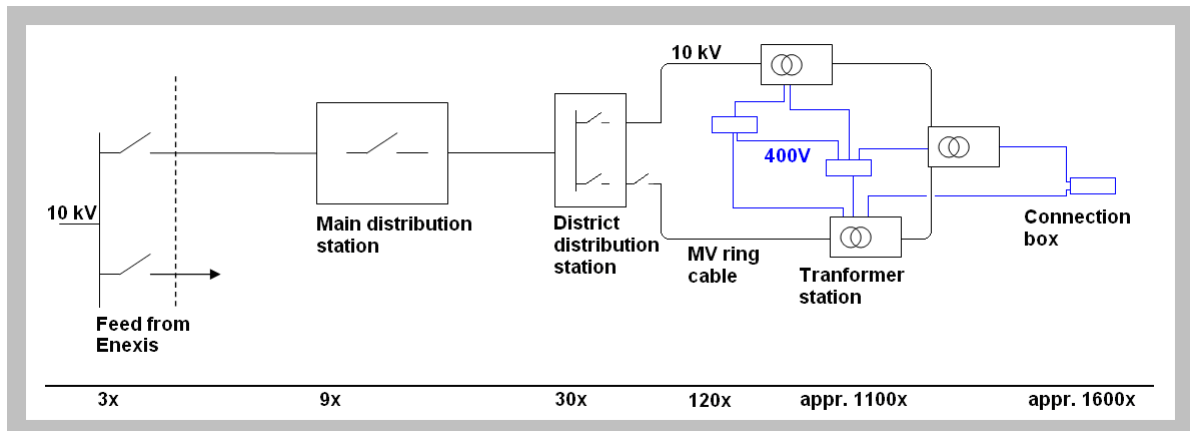


Figure 7: Network schematic Eindhoven

#### 2.3.3.2.2 Margins in existing grids

The existing grids do have some margins and options to expand build into them. Newly designed grid sections in Eindhoven are designed for approximately 2kW per connections while in actuality the peak load is 1 kW per connection average. In addition the design often offers some features that allow easy expansion of the capacity to 2,5 kW per connection. Older grids were designed for significantly lower loads and therefore the capacity surplus of existing grids is very diverse.

Laborelec has performed a study in which they looked at existing grids in representative districts throughout the Netherlands and analysed what development scenario's they could cope with and what would present capacity problems. They looked at electric transport, heat pumps, PV, CHP and combinations of technologies. The main conclusion from this report was that most existing infrastructures can cope with most reasonable developments of technology scenarios. The problem that many in the sector expected with the development of DG in urban areas doesn't materialize. In fact PV and CHP don't present a significant problem in any of the districts analysed.

The real capacity problems appear when even modest penetration of electrical heat pumps or electric cars are introduced. All scenarios cope with air-conditioning but heat pumps for heating present a problem at even the lowest penetration percentages. The same goes for loading electrical cars when the loading happens uncoordinated. In case owners are stimulated to charge cars at night EV doesn't present a problem to most existing grids.

#### 2.3.4 Drivers for change

Drivers for change are there on many levels. In the previous subsections a number of tensions in the current regime have been identified. The introduction of new technologies and the fading separation of producers and consumers are changes that have resulted in tensions within the sector.

This subsection will present the drivers that have presented themselves outside the (influence of) the sector. These drivers originate in wider societal ambitions which happen to

influence the societal expectations and needs from the energy sector. They materialize in policy that is mostly formulated at the European level. The European Commission has formulated three objectives for future (smart) grids to accommodate. They are: sustainability, the European internal market and security of supply. These goals have been translated into the 20/20/20 target and the 'green paper' outlining a strategy for the energy network to reach these goals. (CoEC, 2008; CoEC, 2008b)

#### **2.3.4.1 Sustainability**

Sustainability is internationally the most discussed and certainly the best known of the drivers for change in the energy sector. Well known summits with extensive media coverage like Kyoto and more recently Copenhagen, Reports of the Intergovernmental Panel on Climate Change, the recent turmoil in the academic world described as 'climategate' and things like the Al Gore movie have all contributed to a vast societal awareness of this problem.

Internationally there have been a series of international agreements on environmental goals to which the international community voluntarily committed. Kyoto amongst others has shown the relative value of these agreements since infringements usually go unpunished. Within Europe the international agreements have been translated into internal sustainability goals and policy to realize them. The main sustainability policy document relating to energy networks is known as the 20/20/20 policy. (CoEC, 2008) The recent Copenhagen summit has not significantly changed these ambitions. It states that the EU will:

- cut greenhouse gas emissions by at least 20% (binding target) of 1990 levels (30% if other developed countries commit to comparable cuts);
- increase use of renewables (wind, solar, biomass, etc) to 20% of total energy production (currently  $\pm 8.5\%$ );
- cut energy consumption by 20% of projected 2020 levels - by improving energy efficiency.

#### **2.3.4.2 The European internal market**

An open internal market is one of the cornerstones of the European union. Since freedom of movement of goods was introduced energy was part of this freedom. Only for gas some transition period towards this freedom was arranged. In the case of energy networks the common market is expected to promote efficiency and stimulate innovation. It should provide the citizens of the EU with new additional services and competitive prices.

Energy systems were always considered to be self funding. The EU wishes to maintain this fact and needs the free market to attract investors to the energy sector. A clear and stable legal framework is main precondition for stimulating private sector investment in generation and network facilities. The third internal energy market package will introduce changes to the regulation like rules for unbundling and collaborative network operation. (CoEC, 2008b)

#### **2.3.4.3 Security and quality of energy supply**

This aspect has always been a major concern in the energy sector. There are two factors that play a part in this. These are the external availability of energy and the internal reliability of distribution.

The external availability of energy is always an issue. Natural reserves of energy have always played a significant role in international politics. Many wars have originated from securing the supply of energy. For the European union to be less dependant on external parties like OPEC for oil and Russia for gas it is deemed important to diversify the sources of energy. A bigger percentage internal generation from RES and diversifying external suppliers and supply routes are part of this strategy. Sufficient internal transport capacity also contributes to the flexibility of supply routes needed.

Modern society depends heavily on the secure supply and availability of energy. Both the perceived inconvenience by citizens and economic consequences are significant when disruptions occur. Today the scale, quality and safety of European Energy networks is unique in the world. The Dutch electricity network is one of the best, even compared to other European networks. With an ageing infrastructure that needs to fulfil changing needs maintaining the current standard of operation will become a point of attention. Maintaining or improving this standard is one of the challenges set by the European Commission for future grid developments.

### **2.3.5 State of art developments**

This subsection will look into the (technological) developments in the field of smart grids. There are multiple developments in the energy sector that influence the development of smart grids. These will not be investigated due to the loose connection to the subject of this project.

The three programmes that will be introduced will be objectively reviewed. They were chosen because they are broad programmes investigating integrated 'smart grids', the technical difficulties and their social, technical and economical potential. The projects goals, approach and (if available) results will be presented. Since this is a small and arbitrary selection of research programmes no further conclusions will be formulated.

This chapter will serve to provide evidence that there are niches in which:

- 'smart' technological options have developed to an extend that they are ready for implementation.
- 'market organisations'/'contract types' are tested that smart technology will support in order to contribute to solving either existing or expected challenges.

#### **2.3.5.1 Olympic Peninsula (U.S.)**

The project was commissioned by the U.S. Department of Energy and carried out by the Pacific Northwest National Laboratory. The goal was to create and observe a futuristic energy pricing concept. The location on the Olympic peninsula was actually faced with capacity problems from its feeder circuit. Rather than heavily investing in additional transmission capacity to the remote location this project made solution possible other than increasing the transport capacity.

The project used automated two way communication at the end-use, distribution and generation level to improve electrical and economical efficiencies through price signals the system sends. It was expected that this would allow decreasing stress on the distribution system by actively engaging traditionally passive resources.

The project comprised a common communications framework on (smart) meters, network and DG; 112 homes; 40 utility water pumps; 2 diesel generators and a micro turbine. Three contract types were introduced for the participating households. They were a traditional fixed price contract, a time of use contract (like the Dutch day and night tariff) and a real time market tariff.

The central organizing element of the project was a shadow market that provided incentive signals that encouraged DG and demand response to contribute to congestion management. On real debit accounts the residential customers could earn money by adjusting their behaviour favourably compared to their predicted behaviour. Through 5 minute bids for electricity from end users and price for producing electricity from decentralised generators a price was determined and the market cleared every five minutes.

The conclusions from this trial project included:

- The project successfully managed an imposed feeder constraint for an entire year using innovative automated technologies.
- Peak load reduction up to 20% was successfully accomplished.
- Residents eagerly accepted and participated in innovative price-responsive contract options.
- Automation was found helpful for obtaining consistent responses from both supply and demand resources, increasing the predictability of peak loads.
- The ease of participation, automation and ability to override controls may be a key to attaining the needed magnitude of resources.
- Real-time price contracts were especially effective in shifting thermostatically controlled loads to take advantage of off-peak opportunities. (Within the Dutch context this is not yet relevant but with the introduction of heat pumps shortly may become so)
- Modern portfolio theory was applied to the mix of residential contract types and should prove useful for utility analysis.
- Price-market participants responded to incentives offered through a shadow market. The project demonstrated that demand response programs could be designed by establishing debit account incentives without changing the actual energy prices offered by energy providers. (PNNL, 2007)

This project shows the potential of smart technologies. By using smart meters with ICT and new contract forms they managed to prevent expensive expansions of the electricity network while along the way also contributing to reducing total energy consumption. The relevance for the Dutch context is currently limited since the current state and quality of the networks as well as the conventions and values in the sector are different from the US network sector. The project does however show the potential of new developments and should inspire to realize suitable similar innovations within the European context.

### **2.3.5.2 Address**

Address is a European development program that has been started under the Europeans Commission 7<sup>th</sup> framework programme. The objective of the project is to enable active demand in the context of smart future electricity grids. It focuses on contributing to the European Smart Grids Technology Platform's vision of a flexible, reliable, accessible and economic electricity grid. Participants from all over the EU take part in this programme,

including representatives spanning all of the electricity supply chain as well as research organisations.

The tangible goal of the programme is to enable the active participation of domestic & small commercial consumers to the power system markets and the provision of services to the different participants. What makes this programme unique in its field is the fact that it does not only develop technical solutions, identify market potential or analyse transition issues. It addresses all of these subjects individually and aims to integrate the results in three complementary test sites with different characteristics. To do so Address uses a conceptual architecture in which all aspects have a place and in which relations between aspects are made clear.

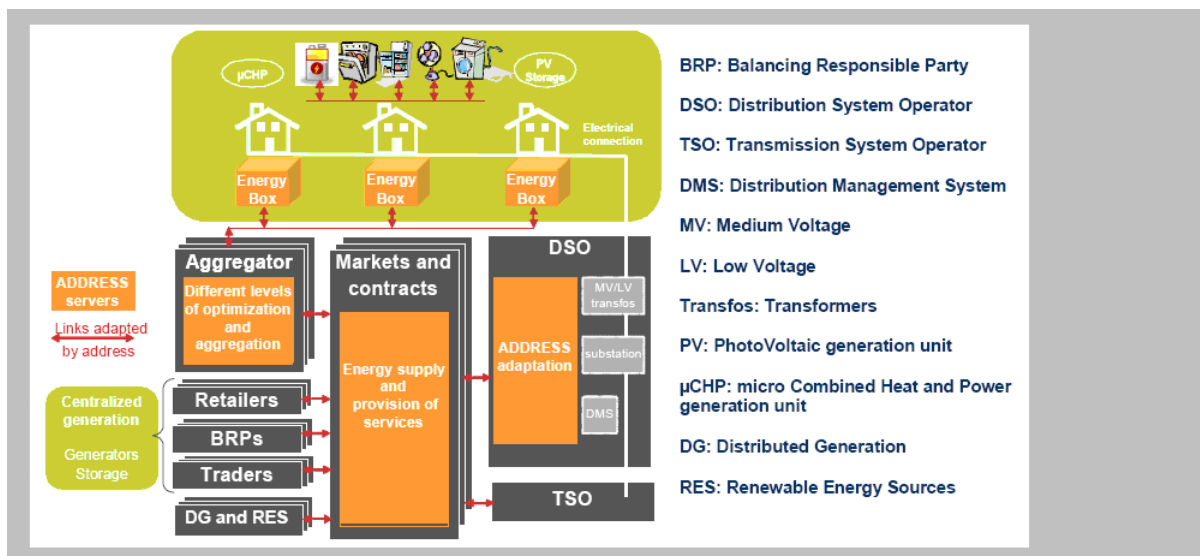


Figure 8: ADDRESS conceptual architecture (Peeters, 2009)

So far the project has identified a number of prerequisites and potential barriers for Active Demand deployment (AD). Technical and economical aspects, consumer acceptance, market access and regulation will always be of importance when realizing AD. Specific barriers for which Address works to find solutions are the acceptance by market participants, regulatory issues, contractual issues, pricing models, information management and transformation risks. (Six, 2010)

The Address programme focuses on AD which is only one of the possibilities of smart grids. It does this however in a very multidisciplinary way, integrating different aspects of the development and involving a broad spectrum of stakeholders. If the programme goals are reached it should result in a very usable product which is certainly within the definition of a smart grid.

### 2.3.5.3 PowerMatching City

PowerMatching city is a project based on the PowerMatcher technology developed by ECN. ECN recognises that electricity flows will increasingly get bidirectional in the near future. A part of the DG capacity installed is intermittent and in case of cogeneration, sun or wind independent of electricity need. As a result the controllability of supply is reduced making balancing of supply and demand increasingly difficult.



ECN has formulated that in order to cope with these changes the electricity grid needs a two-way coordination system that optimizes the use of multiple assets, both generators and loads attached to it. The 'Power Matcher' is an ICT solution to this that relies on smart meters as key enablers. The system provides near real time feedback on demand and supply of electricity and provides (financial) incentives to manipulate the controllable generators and loads in order to locally match supply and demand.

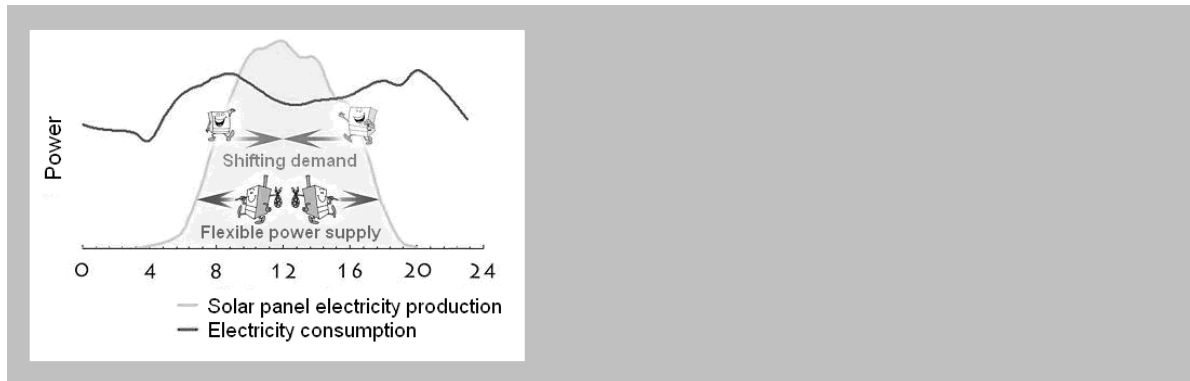


Figure 9: PowerMatching City matching concept

The project assets connected to the system include 12 micro CHP installations, 13 hybrid heat pumps, 300 m<sup>2</sup> PV panels, smart washing machines, electrical cars, a 2 MW wind farm and a 30 kW gas turbine. The goal for this field test is to collect data on the willingness of participants to exchange comfort for financially rewarded flexibility. ECN further hopes to analyse the scalability of the concept and whether the technology is capable of matching supply and demand in a mass-scale adoption scenario.

## 2.4 MLP on transition in electricity

This section will look at the electricity sector and its potential for technological transition. It is important to be able to predict what changes might happen since this will allow for realistic and coherent choices to be made in building a scenario. Based on MLP typology a number of probable characteristics of the development of the energy sector can be predicted. MLP is itself is not designed for predictions but looking at characteristics of transition pathways some likely developments can be identified. A number of influential aspects of the socio-technical regime are more specifically discussed

At first glance there is a situation suitable for sustaining technological transition. There is tension and dynamism in the regime, there are strong and concrete landscape pressures and a number of niche developments have taken place. Public infrastructural regimes are by nature of great stability and possess great inherent resistance to change. This resistance is mainly caused by the high economic value of current infrastructure and conservative regulation. There is however a lot of tension and dynamism in the current regime due to recent changes in institutional configurations concerning European unity and a new market situation due to internationalization and neo-liberal ideologies. Current economical, political and environmental developments are rapidly influencing the landscape which puts pressure on the current socio-technical regime.

*Sector organization*

The general structure of the sector and the recent unbundling are factors that greatly influence ability of the sector to support transitions. The individual responsibility of all parties and general obligation of network operators to facilitate the market makes technological transition in individual sector segments relatively easy. Structural change and sector wide transitions might not be accomplished without a coordinated approach.

The current system of regulation is relatively recently introduced. It is therefore still very much being developed. The goals the regulation system aims to fulfil are very narrowly defined. New developments and challenges are thus far not introduced into the goals of the system. This means that despite the fact that the dynamism resulting from the ongoing development, the regulation is very much a conservative force in the sector. It discourages innovation through first mover disadvantage and the rigid goals prevent adaptation of the system to new situations.

*Technology & Existing infrastructure*

There are large numbers of technical developments in electrical networks. Most developments are aimed at power generation and end use. They are market driven and often regard the electricity grid as a facility. New technologies may shift energy needs towards electricity increasing the total use, other technologies may just increase the relative peak loads. A temporal discrepancy between (decentralised) generation and consumption may lead to local surplus or shortage.

Several technologies do have great potential to contribute to creating a 'smart grid' and solving the challenges facing existing electricity grids. Thus far little societal effort has been made to establish the needs of the grid and achieving the technologies potential for supporting or relieving the grid. Netbeheer Nederland has formulated that it is capable of facilitating most developments as long as there is a timely indication of which developments to facilitate. It is near impossible or at least economically inefficient to prepare for every possible technological transition. Netbeheer Nederland is to issue in the second half of 2010 the results of a scenario study for the future of electricity and gas networks in case of 90% CO<sub>2</sub> reduction by 2040. Both technical and organizational aspects and their financial implications are considered. The uncertainty about the scope of Dutch smart grids should at least partly be cleared by this report.

The scale and value of the existing networks, the economic value, replacement difficulty and risk of interrupted services are all factors that are taken into account when deciding on changes. Without exception these factors are a reason not to discard the existing infrastructure or introduce a completely new system. The existing infrastructure will allow for addition of new technologies and functionalities as long as the main body remains unchanged. Introduction of new functionalities needs a transition period to allow for continued service throughout the process. Newly developed and renovated network sections can be realised including new technologies while predominantly the old system is still active.

### 2.4.1 Socio technical pathway

Verbong (2009) has described a number of possible transition pathways for the energy sector. In these he describes the circumstances to bring them about and the characteristics of the resulting technological transitions. Looking at situation described and the conclusions formulated above a 'transformation' type pathway is the most likely pathway for change in the energy sector. In addition the end state described for this pathway is in accordance with predictions and expectations of many key players in the sector.

The 'transformation' pathway for technological transition is characterized by significant landscape pressure that leads to gradual adjustment and reorientation of current regimes. Generally niches aren't developed to the extent that they can sufficiently penetrate the system. In case of the electricity networks the size and value of current networks limits the short term penetration potential of new technologies. Though regime stakeholders adjust to the outside pressures the change is often a gradual reorientation of regime trajectories. The new regime will thus grow out of the old regime. In case the electricity sector changes according to a 'transformation' path the current actors remain the main actors in the sector. Due to increased pressures from the landscape, including environmental pressure groups and social movements, and tensions within the regime the current regime actors modify the direction of development. (Verbong, 2009)

This transition pathway described by Verbong will include the development of centralised generation from renewables like offshore wind farms, biomass gasification with carbon capture systems and nuclear power plants combined with increased decentralised production. Small scale DG will be left to the individual consumer which limits the scale of introduction and improves variety of implemented technologies. The impact on the system of DG will therefor remain limited. (Verbong, 2009) In the upcoming years a number of traditional central coal power plants is being developed of which the production is mainly meant for export. (ECN, 2009) In case the political discussion about a new nuclear powerplant is positively concluded the continued importance of central generation seems to be secured for at least another 40 or 50 years. The resulting electricity system will be a hybrid grid that combines traditional central generation facilities with decentralised and smart components, both central and decentral elements contributing to balancing the network.

Developments in the use of energy are left to the individual. This will result in a wide range of local solutions that are chosen. Some areas/municipalities will choose heat distribution networks while others opt for the individual heating solutions like micro CHP or heatpumps. Combined with uncertainty surrounding the scale and form of the introduction of electrical transport the expected growth in electricity demand is might vary between regions.

The current networks are expected to largely remain the same though 'smart' changes and additions will be needed. (ERGEG 2009) The main issue will be the need for network capacity and system balancing facilities. To achieve sufficient balancing in spite of increased intermittend generation, strong demand management will be needed. (Verbong, 2009) Smart technologies including metering will contribute to these challenges in balancing and demand management. (ERGEG, 2010)

## 2.5 Conclusions

- There is no consensus about the exact specifications of a smart grid
- Landscape pressures and Niche developments are available to trigger a technological transition in the sector
- There is an inherent resistance against transition but also a lot of tension and dynamism that favor transition within the current socio-technical regime
- The public sector needs to define a direction for the energy sector and direct or guide developments
- A Hybrid grid is the most likely future for the Dutch electricity network

### ***There is no consensus about the exact specifications of a smart grid***

The first and most predominant conclusion is that there is not yet consensus about the specifications of a 'smart grid'. It can be argued that there can't be a detailed general definition of 'the' smart grid because a smart grid will be different depending on the situation in which it is developed. This would mean sets of characteristics and specifications defining a smart grid should be situation specifically developed. For the Dutch context there is not yet consensus about the specifications of a Dutch smart grid. The ERGEG definition used in this report is the most detailed definition available for the Dutch context.

*"Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."* (ERGEG, 2009)

What is clear about smart grids is that information and IT will play a big role in future energy systems and network operation.

### ***Landscape pressures and Niche developments are available to trigger a technological transition in the sector***

The number of times smart grids are mentioned in both literature as policy documents are testimony to the fact that there are drivers as well as technical possibilities to realize smart grids. On the landscape level there are forces pushing for change in the energy sector. The social and political willingness to achieve energy transition is there though it hasn't been translated to actual commitment yet. Both the dependency on a limited number of countries with often politically unstable or inconvenient regimes as the need to improve environmental sustainability are strong factors empowering the drive for energy transition. In the niche level several technological and market developments have spawned and have proven to be ready for penetrating the current socio-technical regime.

### ***There is an inherent resistance against transition but also a lot of tension and dynamism that favor transition within the current socio-technical regime***

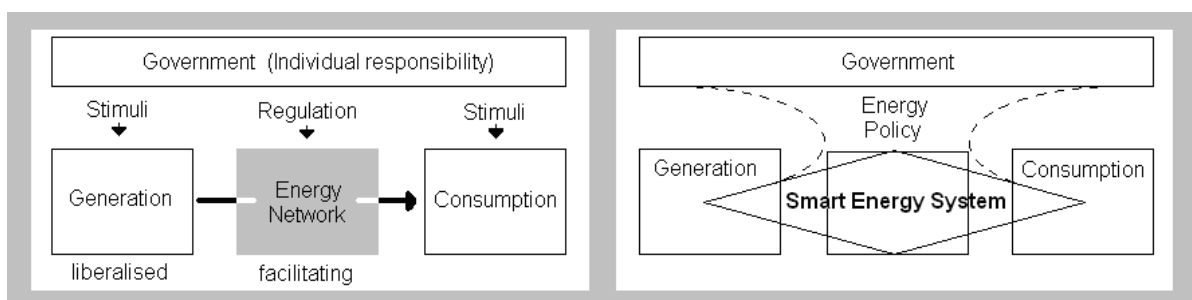
Public infrastructural regimes are by nature of great stability and possess great inherent resistance to change. This resistance is caused by the high economic value of current infrastructure, high cost of network wide changes and traditionally conservative sector regulation.

The current regime however shows a lot of dynamism and tension due to the ongoing unbundling process, recent liberalization of parts of the market and the continued internationalization of the energy sector.

***The public sector needs to define a direction for the energy sector and direct or guide developments***

Despite the proclaimed societal willingness and technical possibility we are a long way from achieving smart grids. Until a structured societal approach to energy is adopted, the development of energy networks remains reactive and a pro-active development of 'smart' networks will be near impossible. The government is looking at the free market to take up the challenge to provide energy transition through innovation and development. In order to stimulate this they have liberalized the energy market as far as possible, keeping those parts of the sector in public ownership that are critical to ensuring quality and safety of energy supply. This resulted in the energy networks and operators thereof being split off and regulated. The government now stimulates market initiatives in the privatized parts of the sector for achieving a sustainable technology transition. The network regulation is focused at securing the public interests that the networks represent. (Figure 10) This general approach presents two problems to the development of smart grids.

The unbundling isolates innovations in either generation or consumption making system integration more difficult. This prevents the sector from being totally reformed, limiting developments to adjustments and localized innovation within the existing system. Secondly the regulation, and the interests it protects, restricts the ability of the networks to pro-actively participate in innovations. Current regulation promotes passive network operators that reactively facilitate the market. The regulators focus on the existing interests and lack of motivation to incorporate other public interests in regulation makes it very unlikely network operators will instigate change without public consensus.



**Figure 10: Current situation energy sector; Alternative suited for achieving sustainability**

***A hybrid grid is the most likely future for the Dutch electricity network***

Based on the current state of all three MLP levels it seems a Hybrid grid is the most likely future for the Dutch electricity network. This hybrid grid will include both central and decentralized generation and will utilize smart technologies to let both types of generation as well as active demand to contribute to balancing supply and demand. This hybrid grid type will not require major rebuilds of the existing electricity networks but can be realized by 'smart' replacements during routine maintenance and adding of smart components like smart meters. The transition process associated with hybrid grids will allow the current stakeholders to remain the key players.



### 3 Realistic worst-case scenario for Eindhoven 2040

This chapter will describe the development of realistic worst-case scenario for the 2040 loads on the electricity grid in Eindhoven. It will present the framework, underlying data, assumptions and resulting projection.

The choice of scenario is important because it determines the outcome. The scenario framework needs to ensure the scenario is based on a set of consistent and realistic assumptions. The projections will only be an impression of what the future could be. Different assumptions would lead to different results. Understanding of the scenario framework and assumptions is vital to placing the results in the appropriate context.

The goal of the scenario as expressed in chapter 1 is to generate an idea of what maximum investment could lie ahead for Endinet. The scenario developed should be a worst-case scenario seen from the perspective of the electricity grid in Eindhoven. It will be based on a general scenario for the development of the Dutch economy by the CPB that was subsequently translated to the consequences for the energy sector by ECN and Telos. The choice of scenario framework is explained in section 3.1.

The capacity of the electricity grid is based on the peak loads it is expected to handle. The projected 2040 peak loads will be ascertained through two steps. These are the extrapolation of normal electricity use and the addition of technological change. First the representative annual usage for connections in Eindhoven will be extrapolated using the Global Economy (GE) scenario figures. (CPB, 2006) Using the current Energy Data Services Nederland (EDSN) electricity load profiles in combination with this extrapolated representative annual use data will result in an extrapolated basic electricity load profile per connection. This will be described in section 3.2.

The second step will include some assumptions on the technologies chosen by individual users. The effects that these technologies have on the energy use, usage pattern and peak moments will be estimated and added to the peak loads from the earlier extrapolated energy use profiles. These choices include the introduction of individual heat pumps and electrical transport. This will be further elaborated upon in the section 3.3. Section 3.4 will conclude the scenario and see the aggregation of assumptions into a projected load profile per connection.

#### 3.1 *Choice of scenario*

This section will present the basic framework on which this scenario is built. First the aspects that constitute a worst-case scenario are introduced. In the second subsection the framework options will be presented and based on the goals described in chapter 1 and the worst-case aspect introduced in subsection 3.1.1 the framework will be chosen.

##### 3.1.1 Worst-case aspects

What aspects and parameters constitute a worst case scenario for a electricity networks is determined by making an inventory of the challenges for networks described in literature, issues mentioned by several sector stakeholders during interviews and the issues mentioned in their policy and vision documents.

There are two general concerns that are omnipresent in literature and sector reports. The first concern is the possibility of increases in peak loads. This could be caused by either an increased total electricity use or by changing usage profiles. Peak loads are the values that determine the network capacity needed. In case the peak loads increase additional investments in the network will be needed to prepare the networks for the future. Factors influencing the total electricity use and the usage profiles are the economical growth, social developments, developments in the energy system and choices in end use technologies.

The second concern is the large scale introduction of decentralised intermittent generation. The current system is based on one way load flows and centralized system balancing. When DG contributes a relatively small part of the total production capacity the stabilization can still be done at a central level. As long as the total capacity of intermittent generators is smaller than the base load of the system the system should easily be balanced by the controllable generators. The decentralised generated power should never exceed the demand at any given time. A number of controllable high capacity generators are needed in the central level to be able to maintain the current infrastructure of the system.

For Eindhoven, being an urban environment, it is expected that peak loads in the network constitute the main problem. (Laborelec, 2009) The availability of small scale DG in urban areas on a LV level is expected to stay a niche as long as an individualist approach to reshaping the energy system is chosen. (Verbong, 2009) It was therefore decided to develop a scenario in which all changes in the socio-technical regime are adversely influencing the worst case aspect 'maximum peak loads' on the network.

### 3.1.2 Socio-economic framework

The variables by which the scenario framework is chosen are based on the requirements that result from the research question and goals. First and foremost the goal is to construct a worst case scenario and the scenario framework should have potential to project the 'worst' conditions. Secondly the results should be relevant as means to initiate a discussion with other stakeholders. The scenario should enable and support the relevance of the results.

As a basis for the development the scenario images from the 'Welfare, prosperity and quality of the living environment' (WLO) explorations (CPB, 2006) are used. The WLO project has drawn up four possible scenarios for the future of the economy and environment in the Netherlands. These scenarios are based on different policy options that are shown in Figure 11. The horizontal axis shows the extent to which governments take an active role in regulating (public) interests. The left of the axis represents a bigger more active government and the right a rather more liberal and passive government. The vertical axis shows the extent to which there is international cooperation in serving the public interests. The international cooperation could include setting targets, regulating national performance, setting technological standards and integrating markets and systems.

The scenarios project images of the future based on a set of consistent assumptions about long term trend developments. Short term deviations from these trends like the current crisis are not accounted for.



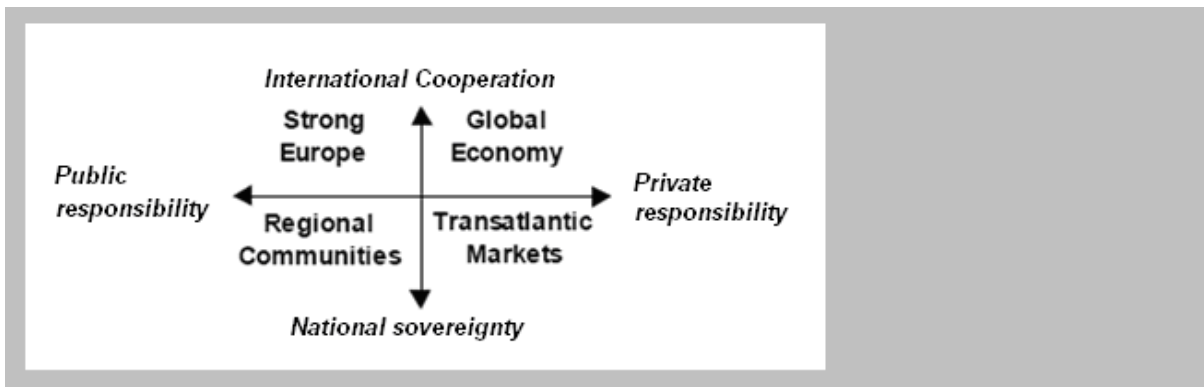


Figure 11: 'Welvaart en Leefomgeving' scenario's (CPB, 2006)

This 2 axis matrix results in four scenarios:

- Regional communities is the scenario in which national sovereignty is important. There is little change in the current social system. Fragmented markets and good welfare systems slow down economic growth. Unemployment is relatively high even whilst labour participation is low. Population even declines from 2020 onwards. There is very little development and innovative power. Universal interests are not addressed at all.
- Transatlantic markets is characterised by national sovereignty combined with belief in the individual responsibility. This results in the development of a single internal market in Europe and the US. Other than in trade there is little or no cooperation between countries. In general competition is limited and thus education and innovation are not priorities. Energy is one of the few sectors where international competition remains fierce. The belief in individual responsibility results in reduced social services and increased differences between social classes. There is a relatively high economic growth, little change in population size and universal interests like sustainability are not structurally addressed.
- Strong Europe is a scenario in which the influence of the European Union is high. Social topics and issues of universal interest are dealt with on a European level. European regulation aimed at social equality and sustainability replaces national arrangements. Economic growth and population development are higher than in the regional communities scenario but lower than the two individualistic scenarios.
- The Global Economy scenario is heavily oriented on free trade, private responsibility and international cooperation. Laws and regulations on sustainability are not as strong as they are in the other scenarios. The average annual economic growth is predicted to be highest in the GE scenario at 2.9%. This scenario also shows a substantial expected increase of population and population density.

The GE scenario is a scenario that combines strong economic growth with an individualist approach to achieving energy transition. These characteristics closely match the conditions leading towards a hybrid system as described in the conclusion of the previous chapter. This system typology is characterised by a traditional network incorporating a wide variety of end use technologies and generation facilities. The wide variety of end use products, the individual freedom to choose energy carriers (gas, heat, electricity) combined with strong economic growth provide uncertainty for the future and could well lead to significant growth in electricity use and/ or peak loads in the electricity network. (Verbong, 2009; ECN, 2009) This makes the GE-scenario the WLO scenario with the highest potential for modelling a worst-case scenario on the first worst-case aspect, peak loads.

Since the introduction of the WLO report in 2006 the Global Economy scenario has become the scenario that is most commonly used in other research projects. It is often used as a basis for sector specific scenarios. The ECN (2009) concludes that GE has increasingly gained the status of reference scenario. The scenario and results based on the GE framework would therefore be recognizable to other stakeholders and be compatible with several other projections. The widespread use of the GE scenario also results in a greater availability of data for developing scenarios based on GE than on any of the other three scenarios. The availability of more and better input data therefore makes it more practical to choose GE as well as it increases the expected quality and relevance of the results.

### **3.2 Future basic electricity load**

This section will present the 2040 extrapolated basic electricity load profile per connection. The method and data elements used in determining it will be discussed in subsection 3.2.1. Subsection 3.2.2 will present the results of this process.

The basic load profile is one of the two elements needed for modelling the future maximum load on the electricity network in Eindhoven.

There are three important elements in determining the 2040 projected basic electricity load profile per connection. They are the representative annual electricity use per connection, the current load profiles and a trend for the development of the annual electricity use per connection.

#### **3.2.1 Method of determining basic electricity load 2040**

This subsection will present the methodology used to determine the projected base electricity use per connection in 2040. It will then continue with presenting the data elements that will be needed to complete this projection.

To determine the load profile for basic electricity use per connection for 2040 the current annual consumption per connection will be extrapolated. New technologies penetrating the socio technical regime will be accounted for separately and will later be added to the extrapolated loads. This allows assuming that the current standard electricity load profiles remain unchanged. The method of extrapolating therefore only includes the representative annual consumption per connection and a projected trend for the change thereof. The trend is based on projections by ECN and Telos for the development of electricity use.

The total representative use per connection is measured in kWh. The standard load profiles show 15 minute periods and the fraction of the annual use associated with that 15 minute period. Dividing these by the time period spanned (in hours) gives the load in kW. The values on this curve are then multiplied by the extrapolation factor determined. (Figure 19: extrapolation of representative current use profile)

$$\text{Use}_{\text{annual rep}} * \text{Fraction}_{\text{load profile}} * (1/\text{Period}_{\text{load profile}}) * \text{Factor}_{\text{extrapolation}} = \text{Projected load (2040)}$$

##### **3.2.1.1 Customer database analysis**

The representative values for the annual electricity use per connection were produced from a database analysis of the invoicing data available. In case a connection had no use recorded for over 14 months the connection was considered to be inactive.

Endinet has 111,410 electricity connections of which 105,308 are active and for which the invoicing system contains billing data that was used to determine the annual consumption. The values determined are the average consumption per connection for the period 2004-2009. There are two types of billing that might apply to a connection. A connection might be invoiced annually or on a monthly basis. Both types were processed differently to establish the representative annual use.

This section will give a brief summary of the method used for analyzing this data. A short overview of the results relevant for this scenario can be found at the end of this subsection. The full report on the results can be found in Appendix 1. The method is extensively described in Appendix 2.

These representative annual electricity use values per connection will later be extrapolated to 2040 using the trend data and applied to the standard load profiles to generate the 2040 basic electricity load profiles.

### ***Annually invoiced connections***

Invoicing contained 109,914 connections that are invoiced annually of which 103,840 are considered active.

The billing and/ or usage data for connections that are invoiced annually is not available in any kind of regular interval. Most connections have 6-8 random intervals for which the use was recorded. It therefore has not been possible to establish the use for a single year, let alone a trend for the development of actual usages per connection. For each connection the postal code, tariff system, physical capacity and the network section to which it was connected is known.

There were 6,074 connections that were deemed inactive through the 14 month criteria. The connections that were considered to be active were subsequently analysed differentiating on the intervals registered for them. The foremost problem in determining representative annual usage values is the fact that electricity use is not constant throughout the year. (Figure 16) This makes extrapolating or interpolating random periods to a single year a high risk of introducing inaccuracies. It was therefore tried to find methods of processing the data without this problem interfering.

First 60,935 connections were identified for which the total registered period was  $[n-1.95 < n < n.05]$ . These periods were considered entire years and for these connections the aggregated usage was divided by the number of days the period spanned and subsequently multiplied by 365.

From the remaining connection single records spanning a single year were identified. A single year was regarded to be any period for which  $[0.95 < n < 1.05]$  ( $347 < \text{nr. Days} < 383$ ) applied. This resulted in 28,000 connections for which the representative value was the value of this single period registration divided by the number of days the period spanned and subsequently multiplied by 365. The growth of the Eindhoven electricity use is 2.5% annually. Since this includes the growth in the amount of connections the development trend of the average use per year is estimated to be less than 2.5%. The average value of representative usages for these connections is expected to be correct though individual values may be off by up to 5% from the real 2004-2009 average.

The connections without period in entire years were analyzed. There were no distinguishing features separating them from the bigger population. There is no reason to assume they are different from the average connection. Additionally the beginnings and endings of the periods were randomly spread throughout the years. The best available way to determine the representative annual use consumption for these connections is extrapolating or interpolating the random periods to a single year. As concluded before, the fact that the consumption of electricity is not constant over the year causes inaccuracies to individual values. The average values determined for these connections are expected to be representative because the periods are randomly spread through the annual usage profile.

### ***Monthly invoiced connections***

SAP contained 1,066 connections in Eindhoven that are invoiced monthly. For these connections the records were grouped and per connection the maximum period within 5% of entire years was determined. These periods started at the most recent record and started between 2004 and 2008.

The aggregated electricity used was then divided by the total amount of days in the period and multiplied by 365. The representative annual usages determined are expected to be between 0% and 2% higher than the average use in the 2004-2009 period. This is caused by the estimated growth of annual consumption per connection that is <2.5% and the fact that the calculated periods start at the last records and in some cases the earliest records are discarded to come to whole years.

### ***Representative annual electricity use in Eindhoven:***

The following values and map resulted from the process described above. The results and maps are more extensively presented in Appendix 1.

EDSN profiles (see Table 6)	Total annual use (kWh)	Number of connections	Average use/ connection (kWh)
E1a	301,143,765	91,713	3,284
E1c	43,395,847	8,664	5,009
E2a	67,779,499	2,736	24,773
E2b	36,082,856	906	39,827
E3	593,972,877	1,289	460,801

*Table 1: representative uses E-connections Eindhoven*

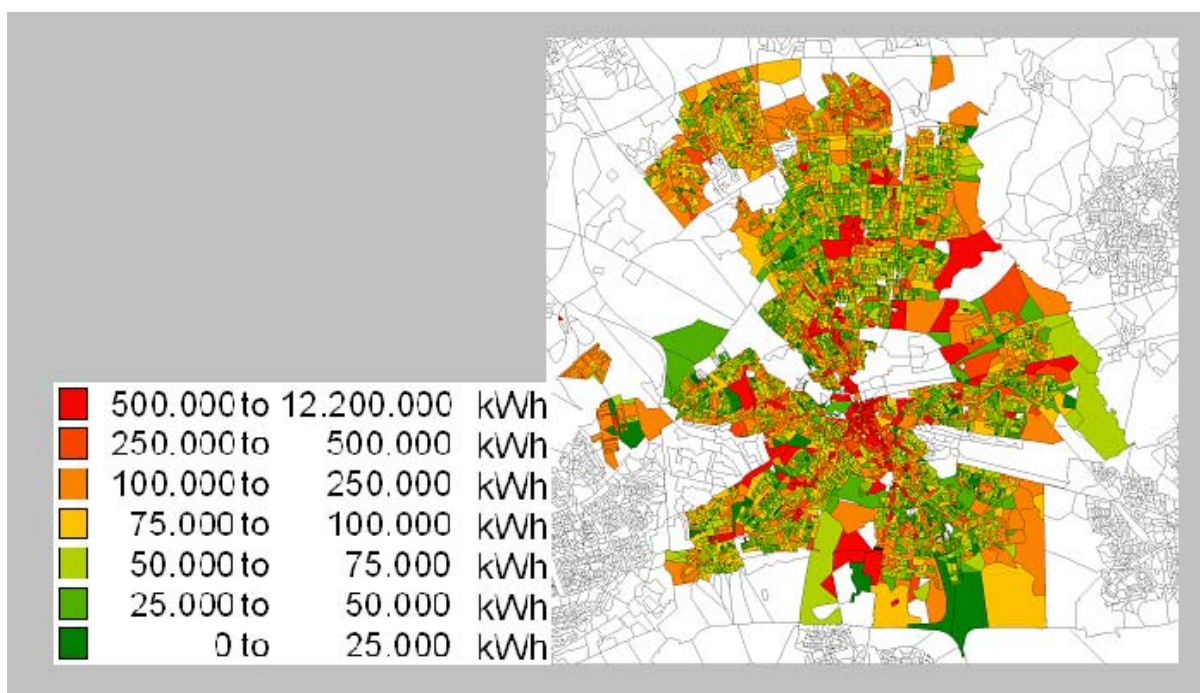


Figure 12: map of annual electricity use per postal code (industry excluded)

### 3.2.1.2 Development trends in basic electricity use

ECN (2005; 2009) and Telos (2008) have translated the GE scenario into projections for the energy system and subsequently the use of electricity. Both studies focus on primary energy use aggregated per sector. Within this project the services, industry and households sectors are relevant.

Both studies extrapolate past trends using the data from the GE scenario. This method does not consider new technologies and possible structural changes in the Dutch energy system. Therefore the development trend will only be applied to the extrapolation of the current use. As previously stated the influence of new technologies penetrating the socio technical regime will be accounted for in section 3.3.

### ECN reference projections

ECN periodically does these reference projections in order to support energy, climate and air pollution policy. The most recent projections are the 2009 actualization from the 2005-2020 estimations of 2005.

The 2005 projections presented a number of situations that were based on the GE and SE scenarios from the WLO scenarios by the CPB. (CPB, 2006) The recent update noted that due to the increased importance of the GE scenario they have only updated their estimations for this scenario.

### Households:

For households the ECN observes that households primarily consume gas and electricity. In 2005 the total temperature corrected consumption of gas was 322 PJ and the electricity consumption was 87 PJ. A mere 8 PJ was delivered through district heating. Other carriers like fire wood or petrol based products were not considered. In 2005 the Netherlands housed 7,091,000 households.

The GE scenario estimates the number of households to increase to 8,315,000 by 2020. ECN predicts the use of gas will decrease significantly over the following 15 years. This is due to

better isolation and more efficient high efficiency boilers. The total gas consumption is expected to be 269 PJ by 2020. For electricity the ECN expects the total consumption to increase to 123 PJ. (Figure 13, 'UR GE' is the updated GE projection) This projection includes the high economic growth in the GE scenario and the associated increase in ownership and use of electrical appliances. It also includes a further introduction and market penetration of more energy efficient appliances.

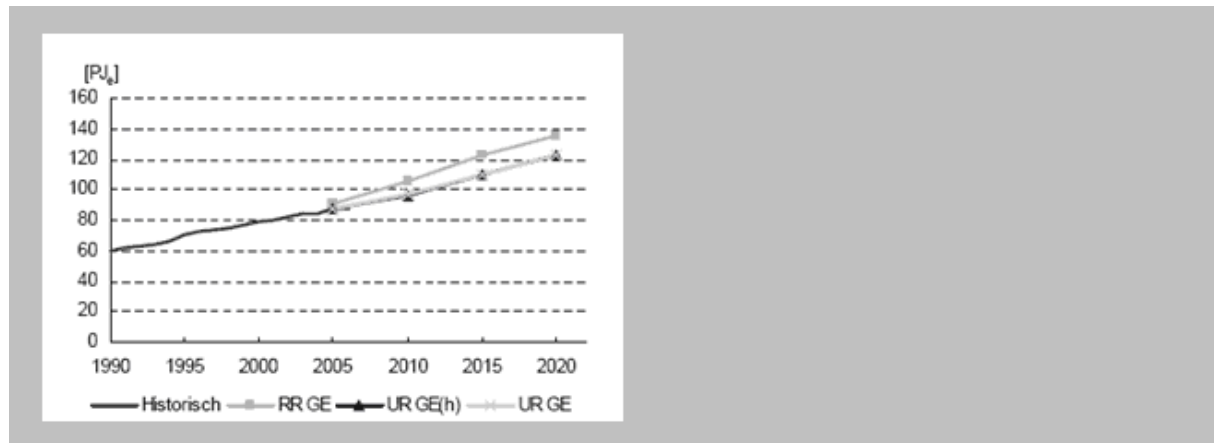


Figure 13: Projection national electricity use households (ECN, 2009)

This results in an average increase in primary electricity use of 1.37% annually (Table 2) over the 2005-2020 period. The graph implies that the increase in aggregated electricity use in households slows down towards the end of the period. The same goes for the development of the number of households. The figures are not available to calculate an accurate trend for the development of average use per households.

	2005	Projection 2020	Increase
Annual aggregated electricity use	87 PJ	123 PJ	41.4%
Nr. Of households	7,091,000	8,315,000	17.3%
Average annual electricity use per household	12.3 GJ = 3.408 kWh	14.4 GJ = 4,109 kWh	20.6%

Table 2: ECN reference projection annual electricity consumption households

#### Services sector:

ECN observes that this sector of the economy mainly uses gas and electricity. In 2003 the total consumption was 203 PJ (gas) and 108 PJ (electricity).

For this sector the projections are based on an estimation of the development of total national employment in employment years. (Figure 14) There is no information available to translate this to the trend for individual connections. It is therefore necessary to assume in what way the size and number of connections will develop. It is assumed that the average connection will continue to represent the same amount of employment years it does today. ECN contributes the development in electricity use to an increased use of ICT and cooling of buildings. They further note that ageing population and scarcity of labour will trigger increased productivity. This results in an average increase in electricity use of 2.18% annually (Table 3) over the 2000-2020 period.

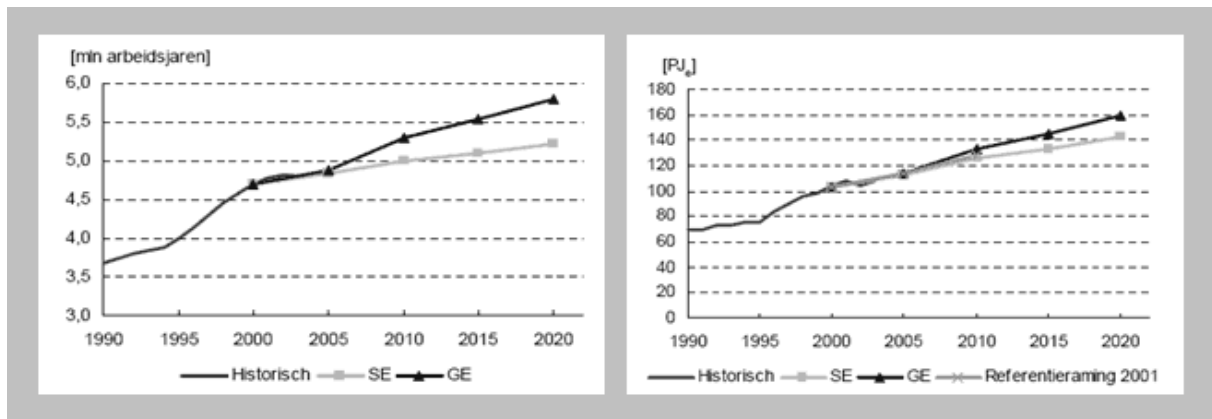


Figure 14: Projection employment years (ECN, 2005)

Figure 15: Projection national electricity use services sector (ECN, 2005)

	2000	Projection 2020	Increase
Annual aggregated electricity use	97 PJ	159 PJ	63.9%
Nr. Employment years	4,700,000	5,800,000	23.4%
Average annual electricity use employment year	20.6 GJ = 5,733 kWh	27.4 GJ = 7,615 kWh	32.8%

Table 3: ECN reference projections annual electricity consumption services sector

**Energiek Brabant by Telos, Brabant centre for sustainable development**

For the province of North Brabant, Telos has proposed ways for the Province to contribute to the energy goals Brabant has set. (Kasteren 2008) Brabant aims to reduce the use of fossil fuels and achieve a climate neutral energy supply. The report uses projections for the energy use in Brabant 2040 based on the WLO- scenarios.

End users	Energy use [PJ]	%
Households	67	17%
Services	73	18%
Agriculture	27	7%
Industry	147	37%
Transport	83	21%
Total	397	100%

Table 4: Primary annual regional energy use North Brabant 2006 (Kasteren, 2008)

End users	Energy use [PJ]	%
Households	98	20%
Services	108	21%
Agriculture	27	5%
Industry	146	29%
Transport	126	25%
Total	505	100%

Table 5: Projection GE-scenario primary annual regional energy use 2040 (Kasteren, 2008)

The values mentioned represent the total energy use for these sectors in the province. Telos doesn't specify what energy carrier will be used to transport this energy. For existing buildings they present a representative example that shows that currently 50-75% of household energy needs are to supply heat. In future this will drop through renovation and new buildings to 50%. The electricity needed per household to operate appliances is expected to remain the same. Currently the heat needed in buildings is predominantly produced using gas as an energy carrier. The figures presented by Telos match the data from CBS (2010) that state that in 2006 61% of the average households' energy needs was fulfilled through the gas networks.

Telos does identify the possibility that the need for heat will be increasingly fulfilled through electricity instead of gas. They expect this to especially be the case in utility and compounded dwelling buildings. The use of electricity for transport is not calculated into the predictions for energy use of households and the services sector.

For the entire 2006-2040 period Telos predicts an unchanging total energy need per household based on the projections made in 'Welvaart en Leefomgeving' (CPB, 2006). It does identify potential to reduce energy use by up to 60%. The GE-scenario is the scenario in which it is least likely this will happen. Individual responsibility, lack of international agreement and strong economic growth will lead to very little, if any, reduction in energy use. Telos further recognises changing technologies and the possibility that this will cause the balance between gas and electricity to change. Most potential changes and reduction measures favour reducing gas use and an unchanged or slightly increased electricity use. This suggests that heat pumps with electrical heating elements are not considered by Telos.

### 3.2.1.3 EDSN electricity use profiles

The EDSN electricity profiles are drawn up annually. They are used by network companies to predict loads of new network sections during the design process.

The profiles are using the following method. EDSN measures the load on 1000 connection every 15 minutes during an entire year. The 1000 connections are divided in 10 categories based on the physical capacity of the connection and the tariff structure that applies. (Table 6)

E1a	<= 3x 25 Ampère, enkeltarief
E1b	<= 3x 25 Ampère, dubbeltarief, nachttarief
E1c	<= 3x 25 Ampère, dubbeltarief, avond actief tarief
E2a	> 3x25 Ampère <= 3x80A, enkeltarief
E2b	> 3x25 Ampère <= 3x80A, Dubbeltarief
E3a	> 3x80 Ampère, < 100 kW, BT<= 2000 uur
E3b	> 3x80 Ampère, < 100 kW, BT > 2000 uur, BT <=3000 uur
E3c	> 3x80 Ampère, < 100 kW, BT > 3000 uur, BT < 5000 uur
E3d	> 3x80 Ampère, < 100 kW, BT >= 5000 uur
E4A	Op het stuursignaal openbare verlichting geschakelde aansluitingen <100kW

Table 6: Profile categories EDSN (EDSN, 2008)

EDSN then compensates for holidays and weather influences using data from the years before. The measurements are aggregated and every 15 minute period is assigned a portion of the total yearly consumption for that type of connection.

The resulting value is a prediction for the fraction of the annual load asked by individual connections in a random 15 minute period. By multiplying the appropriate fraction with the representative annual consumption of a connection the predicted load for that specific time and date can be found.



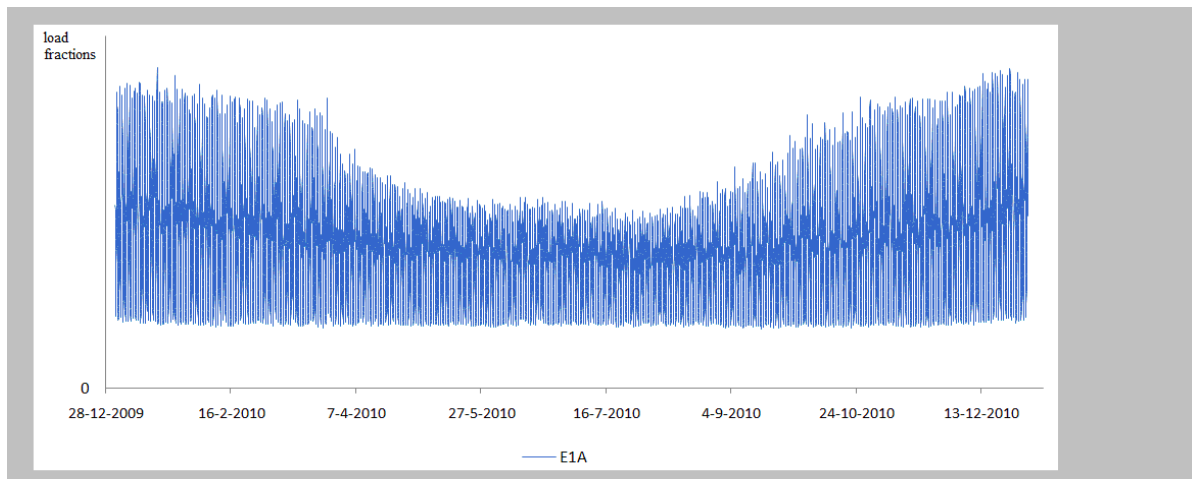


Figure 16: E1a profile 2010 (EDSN, 2008)

The profiles show fluctuations on different timescales. There is a daily fluctuation that differs between week and weekend days. There is also a seasonal fluctuation. The seasonal fluctuations of the E1a profile can be seen in Figure 16 and Figure 17. The daily fluctuations can be seen in Figure 17 and Figure 18. Exact data will not be included in this report due to the confidential status of the profiles.

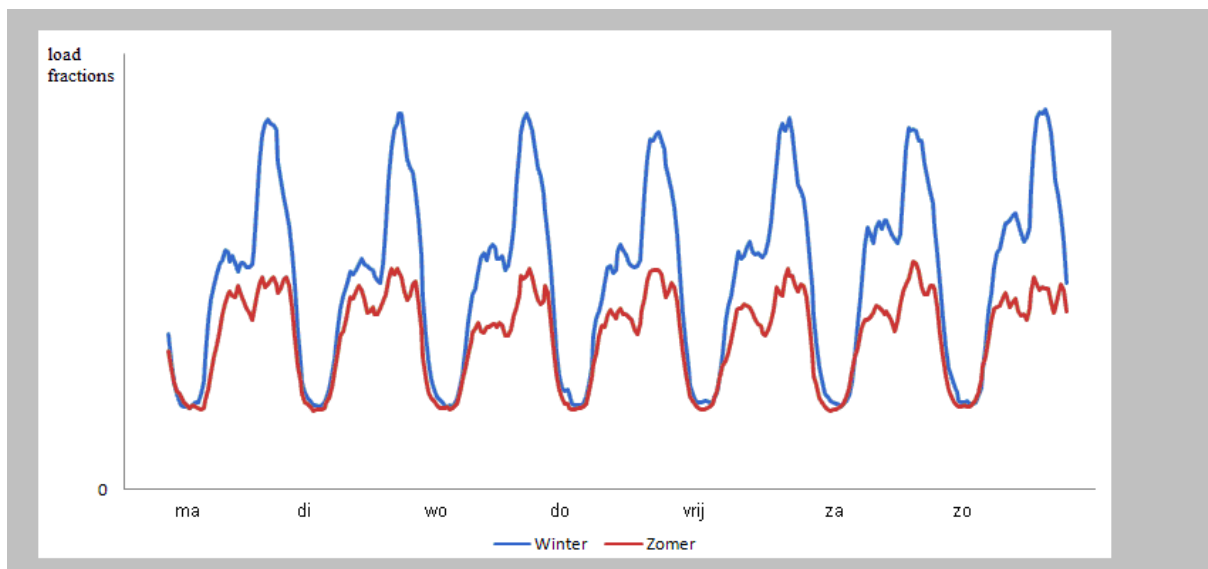


Figure 17: E1a Summer and Winter week 2010 (EDSN, 2008)

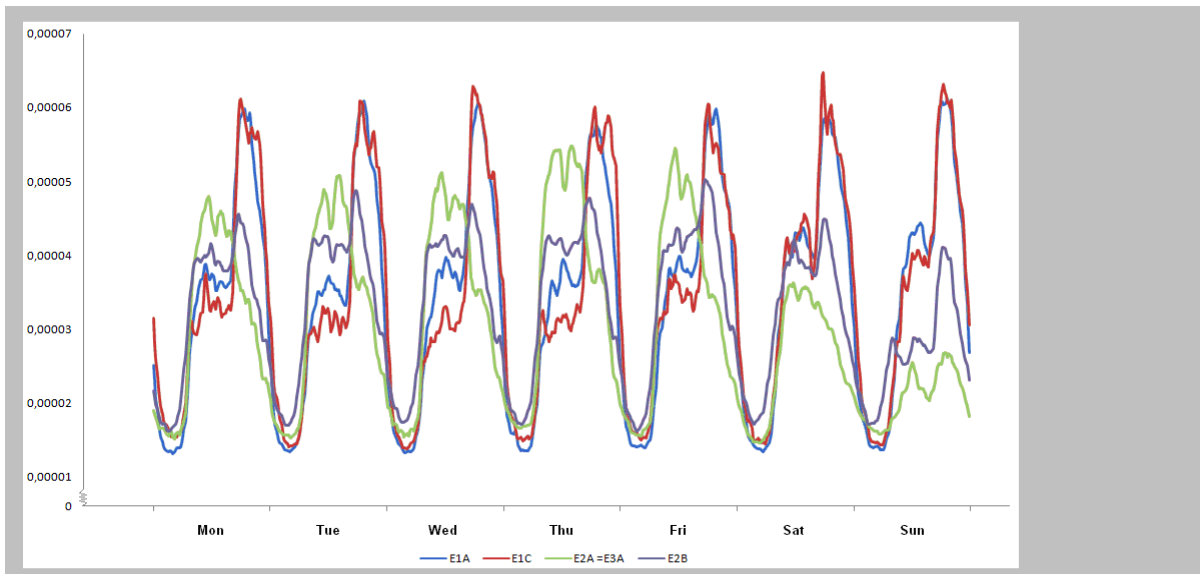


Figure 18: Different EDSN profiles for a winter week (EDSN, 2008)

### 3.2.2 Basic electricity load profile 2040

The previous subsections presented the element and background information needed to underpin the extrapolation of the base electricity use per connection. The definitive values to fill out the equation resulting from section 3.2.1 will be elaborated in this section. Possible limitations and general remarks to the resulting extrapolated electricity use will also be presented.

The representative annual electricity use is already connection specific. The EDSN profiles in are also connection specific. For the extrapolation factor the values need to be defined and allocated to the connections.

All the analysed projections are developed based on the GE-scenario. This strongly suggests that they should be compatible. ECN and Telos have presented studies that have different research methods, goals and geographic and temporal horizons. The data they present is therefore different and can't easily be compared. Close examination has however not shown any of their data and findings to contradict. The ECN data is more specific and by nature better suited to be used as input for this electricity oriented project. Drawback of the ECN projections is they only cover the developments until 2020. Both projections for electricity use imply a linear development of the electricity use for all categories up to (ECN & Telos) and beyond (Telos) 2020 (Figure 13: Projection national electricity use households (ECN, 2009). The 2005-2020 ECN average developments will therefore be assumed for the entire period up to 2040.

The connections that are characterised as E1a and E1c are considered households and their representative annual consumption will be extrapolated from 2009 to 2040 assuming an annual linear increase of 1.37% of the 2009 value.

The connections that are characterised as E2... and E3... are considered services and their representative annual consumption will be extrapolated from 2009 to 2040 assuming an annual linear increase of 2.18% of the 2009 value. For the remaining industrial connections the current telemetry will be extrapolated from 2009 to 2040 assuming an annual linear increase of 2.00%. (ECN, 2005)

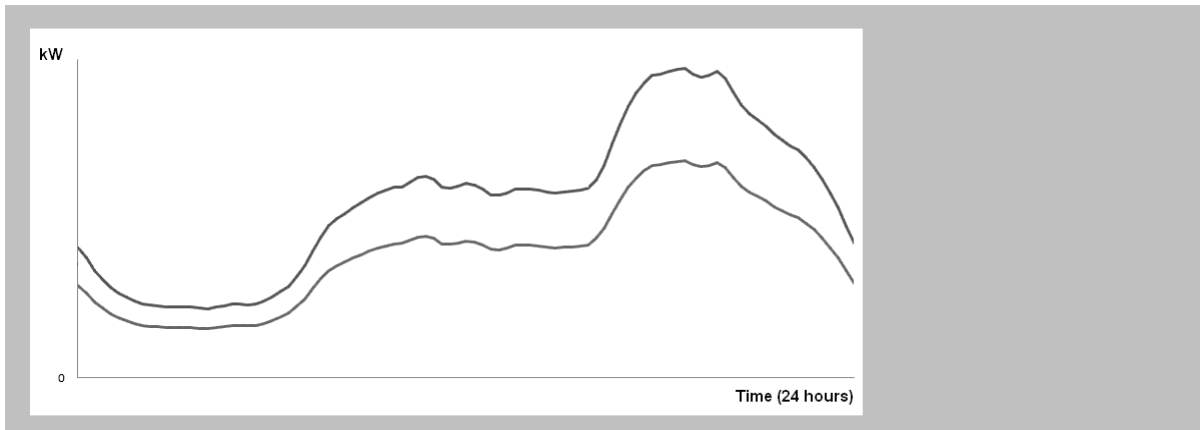


Figure 19: extrapolation of representative current use profile

The WLO and Telos reports suggest that the regional differences are not significant compared to the general trends. The national averages projected by ECN can thus be used for existing build environments throughout the Netherlands. The assumptions made are location specific and will need to be checked or reconsidered for every simulation. For example these base loads will not apply to any environment where a heat distribution network is or will be installed. Nor will it apply to newly (re)developed areas.

### 3.3 Niche penetration based transition of the socio-technical regime

This section will consider the implications of niche penetrations or other influential changes in the socio-technical regime for the electricity load profile.

New technologies have their specific characteristics and subsequent consequences for the total energy use, electricity use, load profiles and reactive power components. When technologies are introduced on a large scale, changing the characteristics of the current socio-technical regime these specific characteristics will have consequences for the capacity and design of the energy distribution networks.

There are multiple niche technologies and market forms that are candidates for penetrating their respective markets. These were identified based on results of the exploratory research done in this project. All these niches, their potential advantages and drawbacks have thus been discussed in chapter 2.

At the urban distribution network level the relevant new developments include PV, CHP, Heat pumps, Electrical cars, Smart meters, Peer to peer energy delivery and District heating. Because it is impossible to regard energy carrier systems as standalone systems the new developments that might influence electricity load profiles include end-use technologies as well as system altering developments and developments in other energy carrier systems.

From these the developments were chosen that meet two criteria. First they need to fit in with the individualistic nature of the GE-scenario. (Subsection 3.1.2) The second criterion is that they should adversely affect the maximum electricity load on the network. (Subsection 3.1.1)

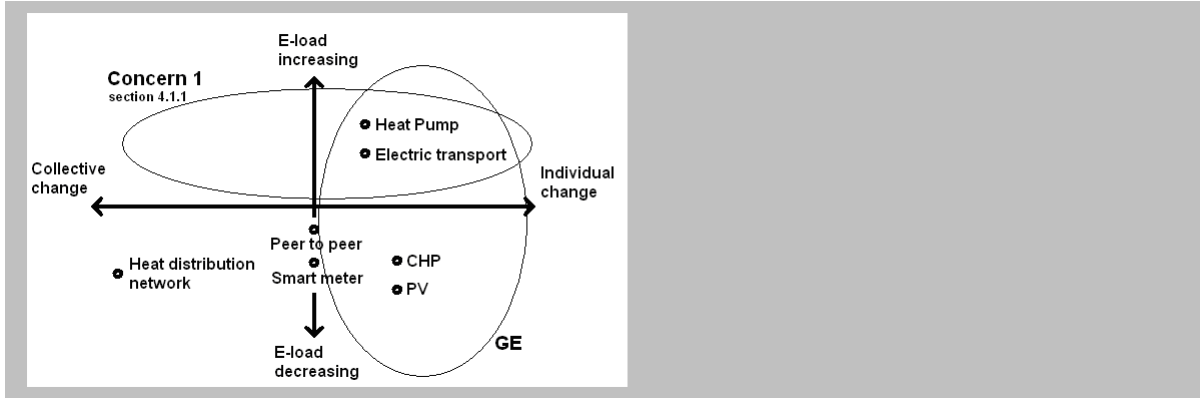


Figure 20: Niche penetrations into Socio-Economic regime

The developments that meet both criteria are electrical cars with home loading and heat pumps. (Figure 20) Both technologies, their implications and the load peaks to be modelled will be discussed in the next subsections.

### 3.3.1 Electrical cars

The introduction of electric vehicles (EV) with home charging will increase the total use of electricity in households. It shifts energy transport away from the petrol distribution system towards the electricity distribution networks. The additional use and maximum load will specifically influence existing distribution networks in case home loading becomes standard. In this worst-case scenario we assume that home loading does.

Different institutes have drawn up projections as to the number of electronic cars that will come in use. The range of projections is shown in Table 7. The ECN projections fall within the range of estimations by different institutions and best complement the other assumptions made based on other ECN projections. Therefore the ECN projections are chosen to build this scenario.

	Min. V&W (2009)	ECN (2009b)	Federatie Holland Automotive (2009)
2020	201,000	250,000	750,000
2033	4,527,000		
2040		3,100,000	

Table 7: Projected nr. of electric cars (full electric & plug in Hybrid) in the Netherlands

ECN predicts the amount of electrical cars to be 250,000 by 2020 and rise to a total of 900,000 by 2040. They additionally foresee a total of 2,400,000 Plug in Hybrid Electric Cars to be in use by 2040. In total electrical transport would represent 35% of the total car transport effort. (ECN, 2009b)

Considering that currently a big battery has a capacity of 36 kWh and maximum period allowable for loading in 8 hours the load per charging car would be approximately 4.5 kW. Allowing a battery to charge between 17.30 and 04.00h would mean an average load of 3.3 kW. (Sluijs, 2009)

Based on the figures presented in Table 8 and the assumption that an electrical car will do 6.5 km/kWh (Min. V&W, 2009) the load on the network can be estimated.

	2000	2040
Total km/year by car in NL	114 billion	192 billion
Cars in use in NL	6.5 million	11.8 million
Average km/car per year 2000	17,500 km	16,771 km

Table 8: Data and projections mobility (ECN, 2009b)

For electrical cars to be interesting they should be rechargeable in at least a single night. In case people just plug in every evening when they get home an unnecessary high capacity would be required. If car charging is evenly spread over 10.5 hours (for example 17.30 – 04.00h) the load per charging car would be 3.3 kW. Current loaders can require up to 10 kW to charge a battery in a couple of hours which means unless measures are taken to spread out the load pattern the peak loads from car charging could be up to 4x higher.

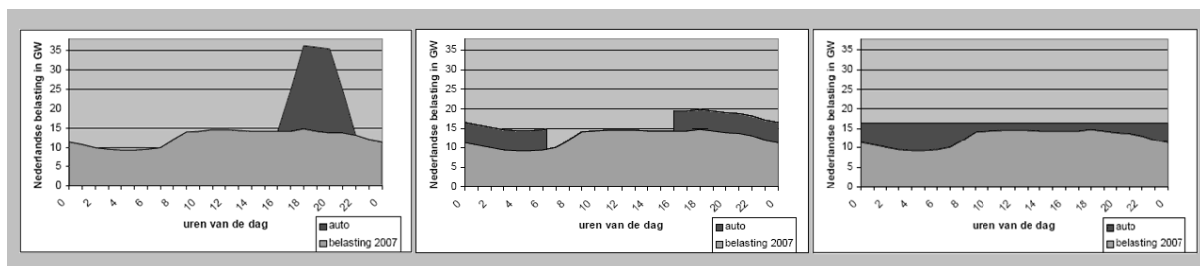


Figure 21: Possible characteristic loads EV: uncontrolled; semi controlled (day/night tariff); controlled.

Even though it is not typically part of the GE characteristics it would be beneficial to the electricity networks if demand was somewhat spread through the day. It seems little individualistic to charge a car during the night instead of on arrival home but the already existing double tariff system could easily achieve a significant result. We therefore assume an even distribution of EV charging between 17.30h and 04.00h.

Every night 19.6% of all cars need to be charged. This would result in an average load of 0.68 kW per electrical car. ( $3.3 \text{ kW} \times 19.6\%$ ) Given a total of 8,315,000 households (Table 2) and 11,800,000 cars (Table 8) there is an average of 1.42 cars per E1a,c and E2a,b connection of which 0.40 per connection are electrical.

This results in a constant load added onto the representative load profile of 0.25 kW daily between 17.30 and 04.00h. The added load then looks like Figure 22.

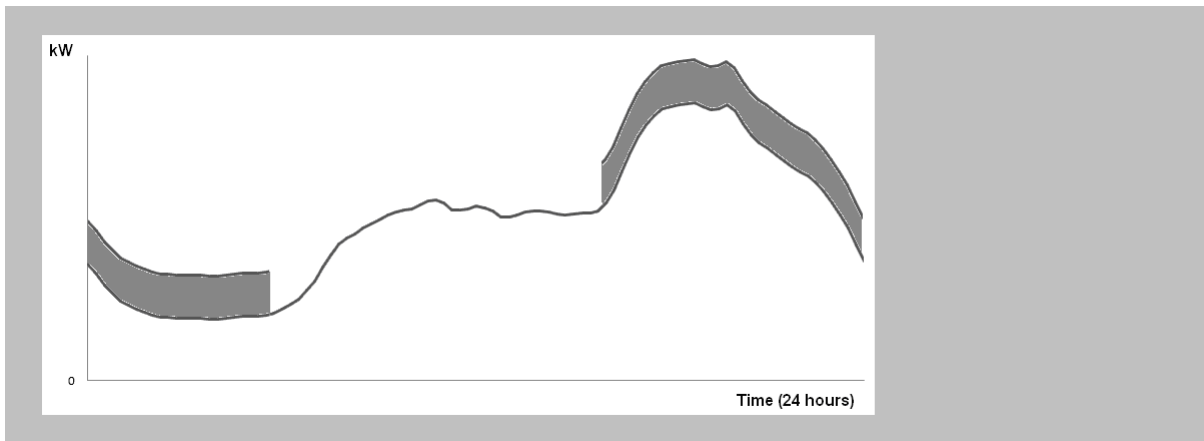


Figure 22: extrapolated base load + electrical cars (17.00-6.00h)

### 3.3.2 Heat pumps

Heat pumps are a new technology that will increase the electricity use per connection. As with the electrical cars this device will shift energy use from another energy network towards the electricity network. With regards to the load profile this technology is very inconvenient for the network. At the time of the maximum the total use the concurrency will rise to very close to 100%. In practice the problem might be smaller, for example in case a number of people decides to install micro CHP's. Given the individual nature of the GE scenario 'might' is the core term in the previous sentence. In case of a mix of Heat pumps and HPC's they will concurrently generate and use electricity significantly reducing the local load problem. In order to model a worst case scenario it is assumed that only heat pumps with electrical heating elements are introduced.

The heat pump will be introduced both in households and utility (small business). For small businesses the capacity of the installation will vary. This will be accounted for through looking at the current gas use at given address. The connections that show a significantly higher gas use will be extrapolated according to the gas use. The degree of penetration in the market is based on the fast introduction scenario from the CO<sub>2</sub>-reduction potential study by Ecofys. They show that 50% of all individually heated houses will have a heat pump by 2030. By 2040 this will have grown to approximately 65%. (Harmsen, 2009)

Heat pumps are not used evenly throughout the year. For a dwelling with the currently required EPC for new dwellings (0,8) the electrical load of a heat pump is expected to average 2.2 kWe during a standard winter week. The biggest concurrent load is needed during extreme winter weather. During such a week the electrical heating elements will be used for heating purposes as well as providing warm water. In most models of heat pumps the pump itself has a capacity of 2-3 kWe, whereas the heating element needs 5-7 kW. During such a period it is realistic to assume that the concurrency factor is 100%. During a period of extreme cold the load per heat pump thus may become 7 kWe for a prolonged period of time. (Laborelec, 2009b)

Since this scenario is statically modelled at key moments in the year it will suffice to add a single 7 kWe during the peak (winter) moments chosen to the load of those household connections that operate a heat pump. This would mean adding 4.55 kW to the average household connection.

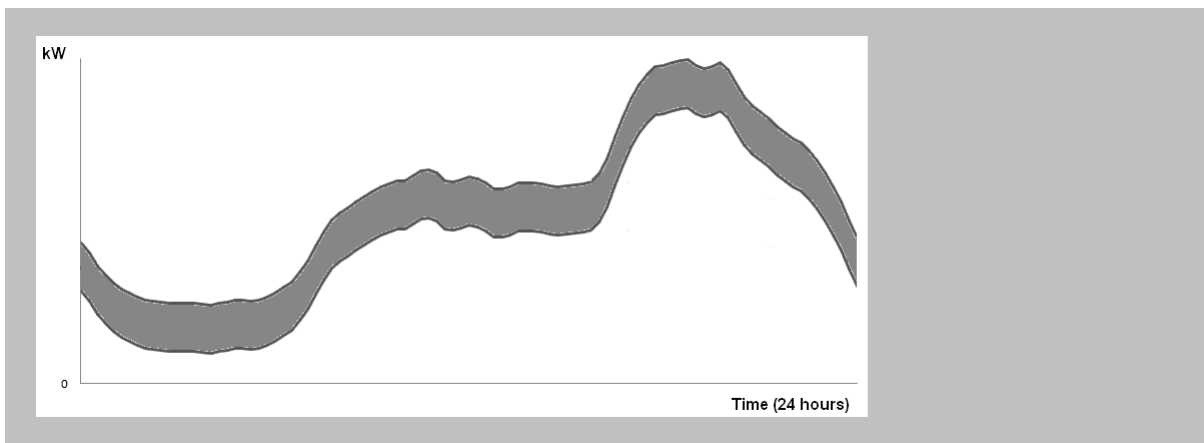


Figure 23: extrapolated base load + heat pumps

### 3.4 Scenario results

The elements presented so far in this chapter get integrated into a single projected load profile per connection. This section will give an overview of the results for Eindhoven. These load profiles are a projections that is coherent with a worst case scenario for maximum loads on the network. It is only valid during winter weeks due to the assumed 100% concurrency of the heat pump load. The total 2040 profile build-up per connection is graphically shown in Figure 24.

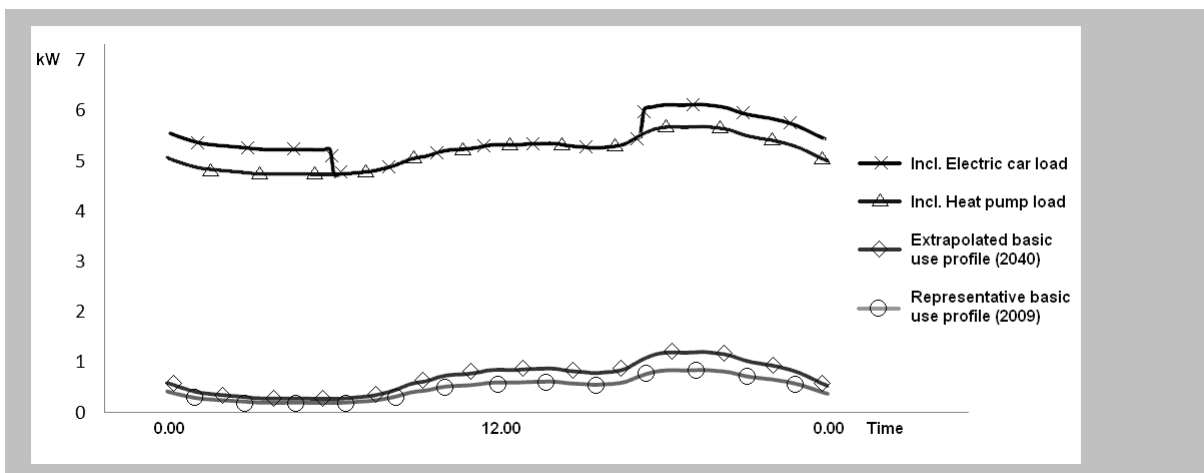


Figure 24: graphic representation of the build up of the 2040 extreme winter load profile

Nr. Connections	Category	Annual index increase		EV	Heat pump
94,092	E1a-E1c	$31 * 1.37 = 42 \%$	$F = 1.42$	+ 0.25 kW	+ 4.55 kW
3,985	E2a-E2b	$31 * 2.18 = 68\%$	$F = 1.68$	+ 0.25 kW	---
872	E3a-E3d	$31 * 2.00 = 62\%$	$F = 1.62$	---	---

Table 9: Realistic worst case GE scenario average electricity loads Eindhoven

### 3.5 Peak loads Eindhoven

The peak moment was determined using the total electricity use (Table 1) and EDSN usage profiles. (EDSN, 2009) The theoretical peak moment was found to be the Wednesday before Christmas between 17.00h and 18.00h. The resulting value as presented below is within 2.5% of the maximum peak load so far recorded in Eindhoven.

The peak loads are calculated using the representative annual usages per connection as determined in subsection 3.2.1.1 and the electricity use profiles from EDSN (EDSN, 2009).

2009		E1a	E1c	E2a	E2b	E3
Total annual use	kWh	301,143,765	43,395,847	67,779,499	36,082,856	593,972,877
Nr. of connections		91,713	8,664	2,736	906	1,289
Average annual use	kWh	3,284	5,009	24,773	39,827	46,801
Peak moment:						
Average peak load	kW	0.78	1.24	4.21	7.80	75.02
Peak load	kW	72,262	10,807	11,539	7,071	96,705

Table 10: Annual usage and peak loads 2009 per connection type

**Total peak load 2009: 199 MW**

The scenario peak loads per connection are determined by extrapolating the peak loads found for 2009 (Table 10) by the factor found in subsection 3.2.2 (Table 9). Then the loads projected for EV and heat pumps are added. After multiplying by the nr. of connections the total peak loads for 2040 are found.

2040		E1a	E1c	E2a	E2b	E3
Extrapolation factor		1.42	1.42	1.68	1.68	1.62
Extrapolated average basic peak load	kW	1.12	1.77	7.09	13.11	121.54
Electrical transport	kW	0.25	0.25	0.25	0.25	
Heat pumps	kW	4.55	4.55			
Nr. of connections		91,713	8,664	2,736	906	1,289
Total peak loads						
Average peak load	kW	5.92	6.57	7.34	13.36	121.54
Peak load	kW	542,835	56,934	20,069	12,105	156,054

Table 11: Peak loads scenario 2040 per connection type

**Total peak load worst case scenario 2040: 788 MW**



## 4 Projected transition investments

This chapter will describe the method used and results found concerning the estimated investments required associated with facilitating the peak electricity demand scenario found in the previous chapter. An estimate for the scenario developed excluding heat pumps is included to establish which costs are associated with which technologies. The method of estimating required investments has been developed in cooperation with a number of senior employees of Endinet and Alliander utilizing their expertise and experience to come to sensible assumptions.

Having an estimate of the financial consequences of the scenario developed is important in both goals set for this project. In order for Endinet to be able to make more efficient, economical and sustainable choices on future network developments it is important to have an estimate of what the required investments are in different scenarios. In an open discussion about the future energy system for Eindhoven this can be helpful.

In order to estimate the investments for facilitating the projected peak demand through traditional means four aspects are important. These are the current network capacity, network load compared to maximum capacity, the scenario peak loads determined in the previous chapter (section 3.5) and the price of network components at all levels. First the capacity of different network levels is determined. Secondly the average load percentage on different network levels during current peak moments is estimated. The third element is load characteristics (variance and concurrency). Finally this factor is used to calculate the investment needed to develop each network level to be able to cope with the scenario loads.

Section 4.1 will present the method and data types used to determine the required network capacity. Section 4.2 will introduce the method for calculating the investments needed. Section 4.3 will present the results of this process. In the results the required investments are presented for both the entire scenario and the scenario excluding the heat pumps.

### 4.1 Method used to estimate required network capacity

This section aims to explain in what way the required network capacity. All the data elements used in determining the projected required capacity are introduced separately. The data elements used are the current network capacity, (projected) peak loads, network load percentages, expansion factor and component prices. Because of the confidentiality of the data, parts of the network capacity and peak load determination are not explicitly described in this public report.

#### 4.1.1 Network capacity

The Eindhoven network is analysed at 7 different levels. These levels follow the network structure presented in Figure 7 (subsection 2.3.3.2.1) and the cable routes connecting them. They are main feeder cables, main distribution stations, transport cables, district distribution stations, MV ring cables, transformer stations and finally the LV cables. For each of these levels the average and total capacity in Eindhoven at that level is determined. Network sections solely serving industry are excluded from the analysis.

For distribution stations the total number and average capacity of sections is determined. For all MV cables the number of cables and average capacity is used. The load percentage at transformer stations is analysed by the number and capacity of transformers. Finally for the LV capacity the number of switch bays connected to the transformers and their capacity is used.

At each of these levels the number of components in the network and their average capacity is determined. At each level the 'n-1' redundancy criterion is used in the Eindhoven network. This means that at all levels and at all times a critical component may fail without the network capacity dropping beneath the peak requirements. In this calculation this is accounted for by reducing the real number of components by the number of cables, sections or cable routes at each level.

The capacity was then calculated for all levels (except transformers) through the following formula:

$$P_{(n-1)} = N_{(n-1)} * U (V) * I (Amp) * \sqrt{3} * \cos \varphi = \text{max. Capacity (MW)}$$

In which:

$N_{n-1}$  = Number of components (n-1)

U = Voltage level (MV= 10 kV; LV= 400V)

I = average component capacity (Amp), (for cables  $I_{nom}$  (G= 0,75 K.m/W))

$\cos \varphi$  = factor representing the difference between real (energy used) and apparent (energy transported) power

Transformer capacity is given in kVA so the capacity at the level of transformer stations was determined by multiplying the average capacity with the number of transformers and  $\cos \varphi$ .

Network level	Max. capacity (n-1)
Main feeder cables	290 MW
Main distribution station	249 MW
Transport cables	352 MW
District distribution stations	299 MW
MV ring	374 MW
Transformer stations	458 MW
LV network	1,526 MW

*Table 12: Eindhoven Electricity distribution network capacity*

#### 4.1.2 Peak loads

Both the current and the total projected peak loads for 2040 have been presented in section 3.5. Since network sections that exclusively serve industry are excluded the peak generated by these industrial connections is also excluded. This means that at both the main distribution level and the district distribution level the loads from a number of industrial connections is subtracted. This results in three different peak loads that apply to different levels of the network.

	2009		2040	Scenario	Scenario (- HP's)
Network section type	Industry	Mixed	Industry	Mixed	Mixed

	Load	Load	Load	Load	Load
Eindhoven total peak load		199 MW		788 MW	331 MW

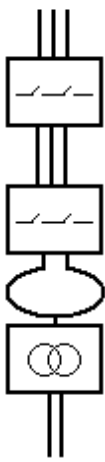
	Main feeder cables	9 MW	190 MW	14 MW	774 MW	317 MW
	Main distribution station		190 MW		774 MW	317 MW
	Transport cables	12 MW	178 MW	18 MW	756 MW	299 MW
	District distribution stations		178 MW		756 MW	299 MW
	MV ring		178 MW		756 MW	299 MW
	Transformer stations		178 MW		756 MW	299 MW
	LV network		178 MW		756 MW	299 MW

Figure 25: Maximum loads at different levels of the network

#### 4.1.3 Load characteristics and utilization percentages

In order to determine the 2040 capacity requirements utilization percentages are used. The basis for further calculations is the current utilization percentage. This is the maximum peak load in 2009 divided by the current network capacity. Table 13 shows the current capacity, current maximum load and load percentage for the different network levels.

Network level	Situation 2009		
	Network capacity (n-1)	Max. peak load (2009)	Utilization percentage (2009)
Main feeder cables	290 MVA	190 MVA	65%
Main distribution station	249 MVA	190 MVA	76%
Transport cables	352 MVA	178 MVA	51%
District distribution stations	299 MVA	178 MVA	60%
MV ring	374 MVA	178 MVA	48%
Transformer stations	458 MVA	178 MVA	39%
LV network	1,526 MVA	178 MVA	12%

Table 13: Capacity, peak load and load percentage situation 2009

For the extrapolated basic use and EV it is assumed that consumer behavior stays the same as it is in 2009. This means that the spread in usages at peak time and the concurrency of these loads remains the same. With these conditions remaining the same it is wise to maintain the same redundancy, and thus utilization percentage, to be sure that the network can cope with local variances.

The heat pumps are assumed to be 100% concurrent loads, every heat pump operating at full capacity at peak times. For the average load the distribution of the load over the connections is identical every time because all pumps are at maximum capacity per connection. With predictability being higher for this type of load the network redundancy can be allowed to drop with respect to these loads. Since the current higher network levels already go up to a utilization percentage of 76% it is safe to assume the Eindhoven network can cope with this percentage. In theory the concurrent heat pump loads can probably be allowed a higher utilization percentage still but since it cannot be proven with the current information 76% is a safe assumption.

The acceptable utilization percentage for scenario's therefore consists of two components. Parts of the projected load for which consumer behavior are assumed to be the same as they are today require the same network redundancy the current network has. The heat pump loads which have a more predictable behavior and cannot locally exceed the projected peak loads only need a 34% redundancy (76% utilization) of the network.

The following formula is used to calculate the acceptable utilization percentage (AUC).

$$AUC_{Total} = 1 / (((load\ share_{heat\ pump}) / AUC_{heat\ pump}) + ((load\ share_{basic + EV}) / AUC_{basic + EV}))$$

In Table 14 the buildup of the acceptable utilization percentage and required network capacity for the LV level is shown as an example. The heat pump load is 457 MVA out of the total 756 MVA peak load. The current utilization of the LV level is 12%. By dividing the load component by the required utilization percentage the required network capacity per component is determined. Once the total required capacity and total peak load are known the total acceptable utilization percentage is found by dividing the load by the required capacity.

Load component		Load share	Acceptable utilization percentage	Required network capacity	Acceptable utilization percentage
Basic use & EV	299 MVA	40%	12%	2,562 MVA	
Heat pumps	457 MVA	60%	76%	600 MVA	
Total peak load	756 MVA	100%		3,162 MVA	<b>24%</b>

*Table 14: example determining required utilization percentage*

## 4.2 Method of projecting required investments

This section will explain the method used to project the investments required to realize the required network capacity at each level. The description is a global outline since the number of current network assets as well as the standard prices are confidential. The standard prices used are all inclusive prices for stations or meters cable.

For all network levels the same method of calculating the required investments is used.

Required network capacity (RNC) = Peak load / Acceptable utilization factor

Required investment = ((RNC / Current network capacity) - 1) \* N<sub>components</sub> \* Component price

## 4.3 Required investments

This subsection will present the results of the process described in the previous subsection. Only the resulting network capacity will be shown. The data leading up to these figures is confidential and therefore not in this public graduation report. A confidential 5<sup>th</sup> appendix will be added for further research and use by Endinet.

The required investments are calculated in 2009 currency, without inflation correction, for the entire period running through to 2040. Table 15 shows the scenario impact of the scenario for 2040 on the network and the cost estimate for facilitating these requirements. Table 16 shows the same results for a scenario excluding the loads caused by heat pumps.

Network level	Worst case scenario 2040 (Basic use, EV and heat pumps)				
	Projected max load	Permitted load %	Required network capacity	Required expansion factor	Estimated required investment
Purchase stations				3.51	€ 10,000,000
Main feeder cables	774 MW	76%	1,017 MW	3.51	€ 45,000,000
Main distribution stations	774 MW	76%	1,017 MW	4.08	€ 45,000,000
Transport cables	756 MW	63%	1,190 MW	3.39	€ 40,000,000
District distribution stations	756 MW	69%	1,102 MW	3.69	€ 45,000,000
MV ring	756 MW	62%	1,227 MW	3.28	€ 105,000,000
Transformer stations	756 MW	55%	1,369 MW	2.99	€ 140,000,000
LV network	756 MW	24%	3,162 MW	2.07	€ 90,000,000
<b>Total required investment</b>					<b>€ 500,000,000</b>
<b>Cost per connection</b>					<b>€ 5000</b>

Table 15: Cost estimate scenario 2040

Network level	Worst case scenario 2040 (Basic use and EV)				
	Projected max load	Permitted load %	Required network capacity	Required expansion factor	Estimated Cost
Purchase stations				1.44	€ 5,000,000
Main feeder cables	317 MW	76%	417 MW	1.44	€ 10,000,000
Main distribution stations	317 MW	76%	417 MW	1.67	€ 10,000,000
Transport cables	299 MW	51%	590 MW	1.68	€ 10,000,000
District distribution stations	299 MW	60%	502 MW	1.68	€ 10,000,000
MV ring	299 MW	48%	627 MW	1.68	€ 30,000,000
Transformer stations	299 MW	39%	769 MW	1.68	€ 45,000,000
LV network	299 MW	12%	2,562 MW	1.68	€ 55,000,000
<b>Total required investment</b>					<b>€ 175,000,000</b>
<b>Cost per connection</b>					<b>€ 1750</b>

*Table 16: Cost estimate scenario 2040 without heat pump*

## 5 Conclusions, discussion and recommendations

Both Endinet and the KENWIB are in the early stages of exploring smart grid developments. This project aimed to contribute to this process by exploring the developments in the field of smart grids as well as generating insight into the future requirements of the electricity network in Eindhoven. This chapter will present the results and conclusions and review them in the context of the goals and research questions that were set.

First conclusions will be formulated answering the research questions posed. (section 5.1) Then the extent to which the goals were reached are evaluated. (section 5.2) Finally recommendations are made for further research both within and in extension of the scope of the goals that were set for this project. (section 5.3)

### 5.1 Results and conclusions

The results are given and conclusions formulated based on the research questions posed in chapter 1.

Research Question 1:

*What aspects and developments of energy networks are described by the term ‘smart grids’, what are the current developments in this field and what future developments might be expected?*

The results relating to RQ 1 are already presented in chapter 2 because they were relevant to understanding the choices made in building the scenario in chapter 3. The bullet point conclusions will be repeated here. For elaboration on these conclusions please turn to section 2.5.

- There is no consensus about the exact specifications of a smart grid  
Smart grid specifications can be very specific to a certain location. The ERGEG definition used in this report is the most detailed definition available for the Dutch context.  
*“Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.”* (ERGEG, 2009)
- Landscape pressures and Niche developments are available to trigger a technological transition in the sector
- There is an inherent resistance against transition but also a lot of tension and dynamism that favor transition within the current socio-technical regime
- The public sector needs to define a direction for the energy sector and direct or guide developments
- A Hybrid grid adding ‘smart’ elements to existing grids and combining central and distributed generation is the most likely future for the Dutch electricity network

Research question 2:

*What would be a worst case scenario for the electricity consumption and expected load for Eindhoven's electricity distribution grid by the year 2040?*

In chapter 3 shows the construction of a realistic worst case scenario for the electricity grid in Eindhoven in 2040. It was shown that there can be several types of worst case scenario. Maximum peak loads and distributed generation capacity are both potential worst case aspects. The scenario developed addresses the maximum peak load aspect. In a scenario based on economical growth and an accent on individual responsibility, heat pumps and electrical vehicles are identified to be developing technologies that present the biggest threat to increase peak loads.

Based on scenarios by ECN, Ecofys and Telos the total annual electricity use in Eindhoven was shown to increase by 80-100% from 1.0 billion to approximately 1.9 billion kWh in this scenario. The increase in peak load will be even more profound rising 280% from 205 to 790 MVA. This shows that in this scenario the maximum load flow increases more than the average load on the network. This means the average network utilization over the year will also decrease even further.

Research question 3:

*In a worst case scenario, what will be the investment needed to meet the requirements for Eindhoven's electricity distribution grid by means of conventional technologies and methods?*

The investment needed to facilitate the realistic worst case scenario developed in Chapter 3 is € 500 million. This number is not corrected for inflation and would have to be invested in the thirty year period between 2010 and 2040. The estimate is based on facilitating the scenario using only the traditional network, without the benefits of new technologies like distributed generation or smart functionalities like active demand. Over 80% of the total required investment has to be invested in the MV network levels, only 20% in the LV network. The total required investment would mean a € 5000 investment per connection.

Load profile, the average peak load and the variance in the individual loads determine what network capacity is required. This is shown in the fact that even though heat pump loads represent the biggest increase in peak loads the price per kW increased peak load is lower than for the basic use peak load increase. Respectively 0,7 million €/kW for the heat pump load against 1.4 million €/kW for the basic use increase in maximum load. The cost projections show that the increase in total annual electricity use is not an important factor in determining the network investments needed.

## 5.2 Discussion

This section will discuss the results, the conclusions and to some extent the process. The discussion will relate these to the goals set and evaluate to what extent these goals were met. This evaluation will finally result in some recommendations for further research. (section 5.3)

1<sup>st</sup> Project goal:

*To generate insight into the future requirements of the electricity network in Eindhoven. The ability to consider the entire lifespan of components will allow for more efficient and more economical and sustainable choices.*



This goal sees to provide Endinet with information that can be used for making long term decisions about investments in Endinet's networks. It is possible to give realistic projections for the developments in total energy use. It has however been proven to be very hard to accurately predict future developments for individual networks. This is mainly caused by the fact that energy carriers are often interchangeable. Energy used for heating can be distributed through gas, electricity or heat distribution networks. Transportation can be powered by petrol, hydrogen or electricity. Only when the choice of energy carrier for specific purposes can be predicted can accurate projections for individual networks be generated.

This project focussed on the future of the electricity network. Given the limitations in projecting future requirements for individual energy networks providing insight into the extremes is the best option. Thus creating a lower and upper limit to the range of possible future requirements. This project aimed to provide the upper limit for the electricity network requirements (research question 2) and the investment that would then be needed. (research question 3) The scenario developed only addresses the impact of increased peak loads on the network. It discarded the potential risk distributed generation poses to network operations. The aspects on which a worst case scenario can be modelled do affect each other. Even though their relation was not researched it stands to reason that both scenarios will positively affect the impact of the effects of the individual scenarios. It is therefore important to realize that the projected result is also the upper limit, the maximum investment requirement, not the 'expected' investment requirement.

The projected required investment is specific to Eindhoven. Whereas the general scenario is based on national projections and therefore valid for most urban areas in the Netherlands the cost estimate is not. Network philosophy, design, operational procedures and prices on which the projection is based are specific to Endinet's networks. It would thus be unwise to simply assume the projected investment requirement to be valid for other urban areas.

## 2<sup>nd</sup> Project goal:

*To explore the developments in the field of smart grids and generate insight into the potential consequences for stakeholders in Eindhoven, in order to initiate and stimulate an open multilateral discussion about developing the future energy system of Eindhoven.*

The exploration into the developments in the field of smart grids has generated an overview of what is considered as part of 'smart grids'. It has shown a broad range of technologies and functionalities to be within the scope. Many stakeholders even include social and market developments thus including the entire energy system in 'smart grid' development.

Whereas the first goal mainly focussed on consequences of developments this goal also includes opportunities. It seems that changes in time, place and form of electricity demand and supply have potential consequences for energy networks and systems. Smart solutions are optional and thus represent opportunities to cope with developments by reducing the impact of consequences these changes have. Obviously choosing to implement smart elements will have consequences of its own but at this point I feel that because 'smart' is still optional it represents opportunities rather than said consequences.

To stimulate a productive discussion about the future energy system in Eindhoven drivers are important to motivate stakeholders to stay involved. Increasing sustainability and

security of energy supply is the main driver for energy transition. It seems that based on the existing drivers sufficient motivation is generated to keep discussions alive. Eventually economic aspects come into play when changes need to be realized. Currently the costs for transition are considered very high resulting in a significant barrier for actual commitment to realizing change. Low energy prices are often blamed for the high perceived cost associated with energy transition. The cost estimate developed in this project shows that significant investments might be needed even when no smart investments are being realised. In actuality smart grids might contribute to reducing the total costs of changing the energy system. I hope this long term investment projection will eventually contribute to an integrated approach of evaluating the economic implications of changes to the entire energy system, including generation, (smart) grid development and consumption.

### **5.3 Recommendations**

The results from this project have answered the research questions posed but both within the scope of these research questions as in the scope of the goals some aspects were not (fully) included. Additionally the process and results present new insights and these give rise to new questions to be researched. This section will present my recommendations for future research that based on the results will contribute to achieving the goal of an Energy Neutral Eindhoven.

With respect to generating insight into future requirements this project has also generated insight into the current operation of the electricity network. An indicator number based method has been generated providing insight into utilization factors at different network levels. The representative annual usage analysis creates insight into current electricity use distribution. The possibility of matching this usage data to both network sections as well as other postal code based databases can in future provide insight into consumer behaviour and contribute to accurately predicting load profiles throughout the network. Further research into energy use and possible correlations with other databases containing demographical data can establish more reliable or specific indicators for energy use.

This project has established an upper limit for required investments by establishing a cost estimate for a realistic worst case scenario. This project discarded the risk distributed generation poses to Electricity networks. I would recommend developing this scenario and estimating the associated network investments needed.

The interchangeability of energy networks make that for decisions on the electricity network to be made similar insight into other networks will be needed. Research into the possibilities, implications and required investments of other options is therefore needed. Hydrogen cars, heat distribution, biogas are amongst the alternatives available. Especially the possibilities of heat distribution networks is not yet fully known in the Netherlands. It is recommendable that we learn from experience abroad with these networks, for example utilizing knowledge and expertise from Denmark to investigate the potential for Heat distribution in the Netherlands.

Further research will then be needed to not only show limits but also differentiate the costs associated with all variables that make up realistic scenarios. Only then can a proper decision on the future energy system for Eindhoven be made considering all technological options and based on all interests including security, sustainability and economic aspects.

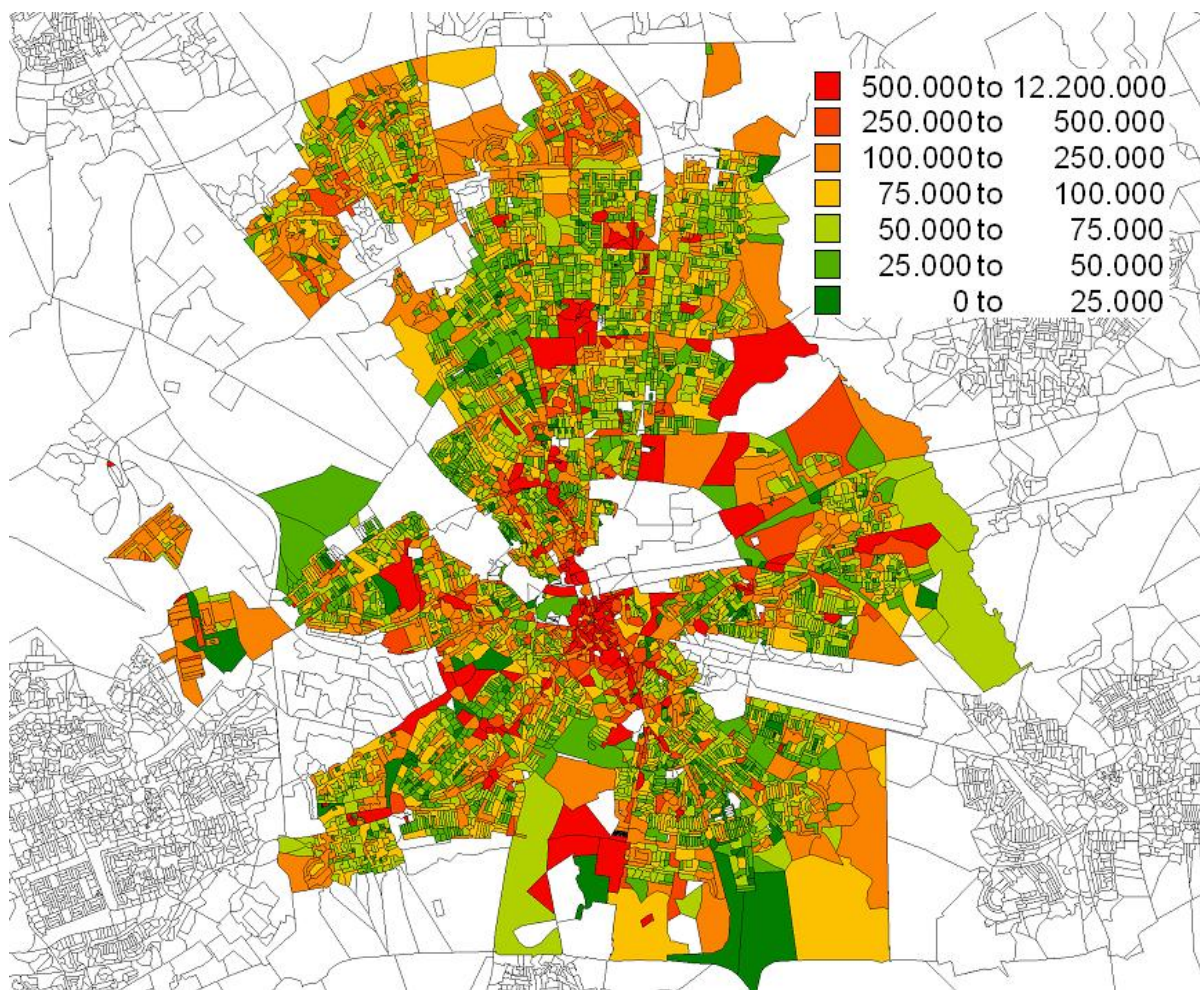
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**Appendix 1: Annual electricity consumption per connection in Eindhoven**

EDSN (2009)	Total annual use (kWh)	Number of connections	Average use/ connection (kWh)
E1a	301,143,765	91,713	3,284
E1c	43,395,847	8,664	5,009
E2a	67,779,499	2,736	24,773
E2b	36,082,856	906	39,827
E3	593,972,877	1,289	460,801

*Table 17: Annual Electricity use per connection type**Figure 26: Map of household and services electricity use distribution by postal code (For privacy reasons the identifiable connections have been excluded.)*



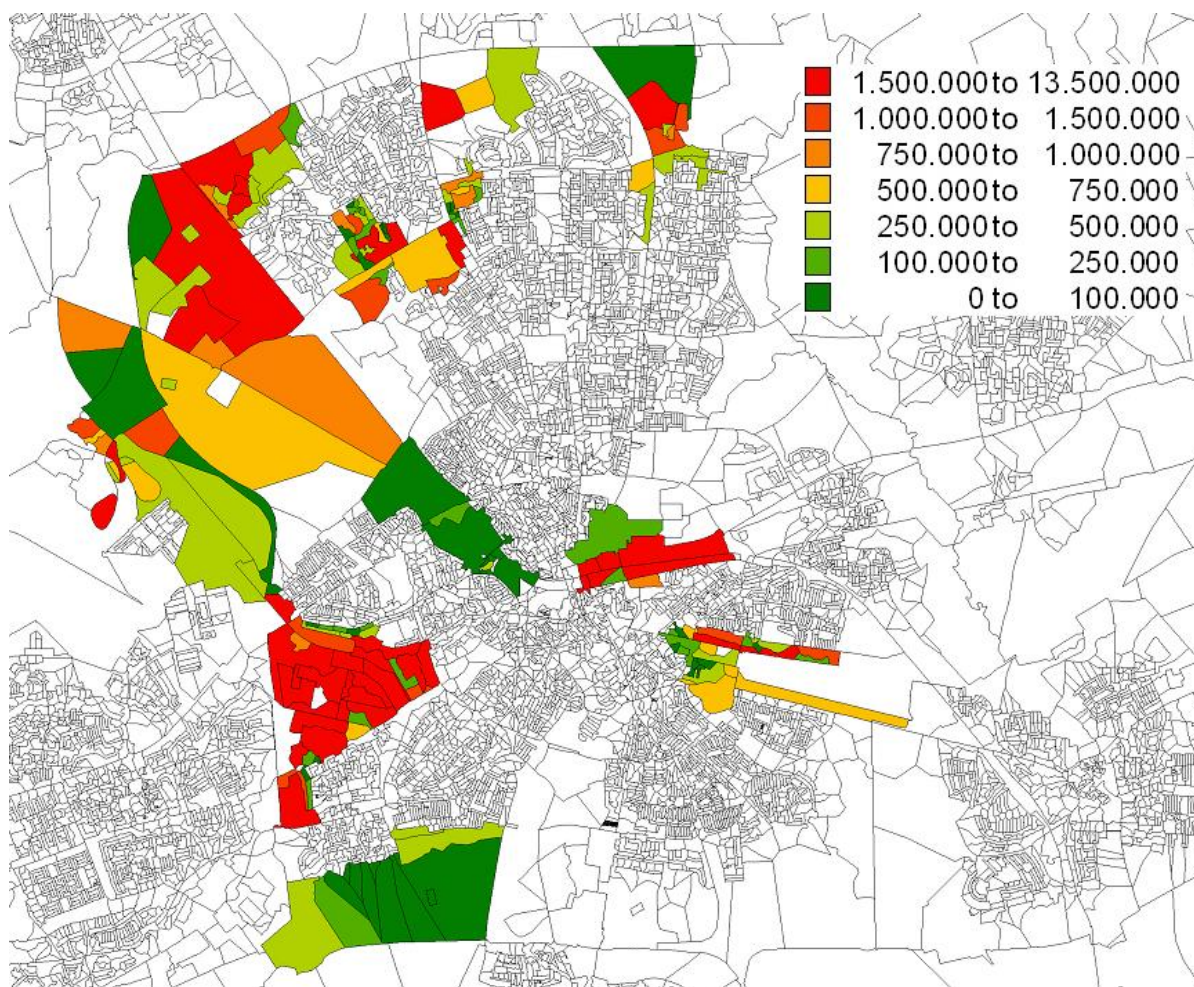


Figure 27: Map of industry electricity use distribution by postal code  
(For privacy reasons the identifiable connections have been excluded.)

### Distribution electricity use

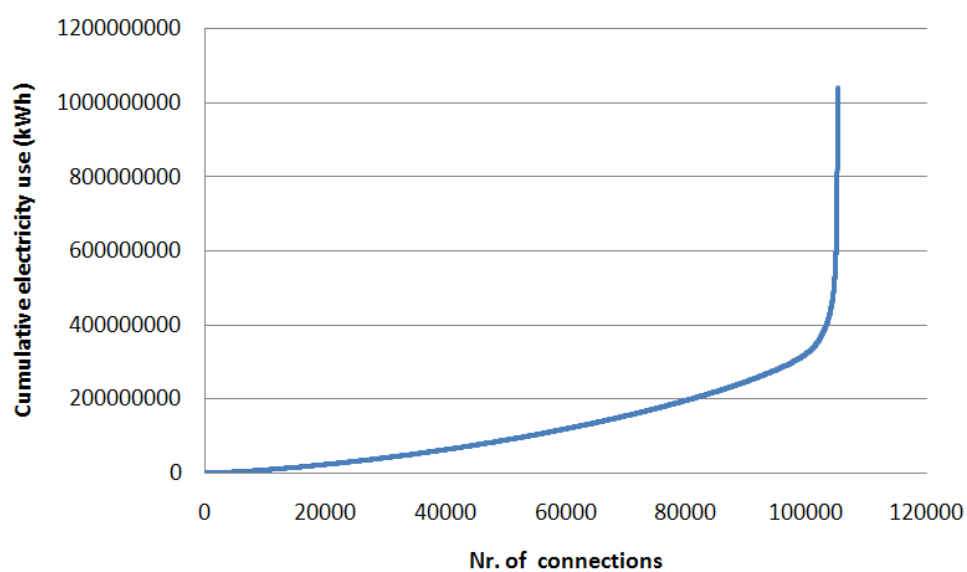


Figure 28: Distribution annual uses per connection

## Appendix 2: Method of determining electricity consumption in Eindhoven

This appendix will provide a short description of the method by which the annual electricity and gas use in Eindhoven was established. A short introduction will provide insight into the data and method used. The results will be presented and then the specific data sets and their handling will be elaborated.

Leading up to this project Endinet was found willing to provide billing data for the Eindhoven region as it was registered in their SAP system. This resulted in a list of over 1.000.000 records concerning electricity and 750.000 concerning gas use in Eindhoven. Separate files from the AEL system and a SAP dump provided the connection and contract capacity of all electrical connections.

Records included:

Install nr; Measuringpoint ID (EAN code); Street; NR.; Zipp code; Billing value; Start date; End date; tariff structure.

The data for both electricity and gas are available in time intervals that are not necessarily entire years. At the moment the client relays the readings they are put into the system. Additionally when the connection or associated information is changed a new time period is recorded in the system. Since the energy use for both media is not evenly spread over the year (for example Figure 29: EDSN usage profile) the representative use per connection per year can not be found by simply dividing the total use by the measurement period. The representative use per connection is therefore in principle the average use per year for the 2005-2009 period. The beginning date, end date and total period has determined the method by which the representative use value was calculated.

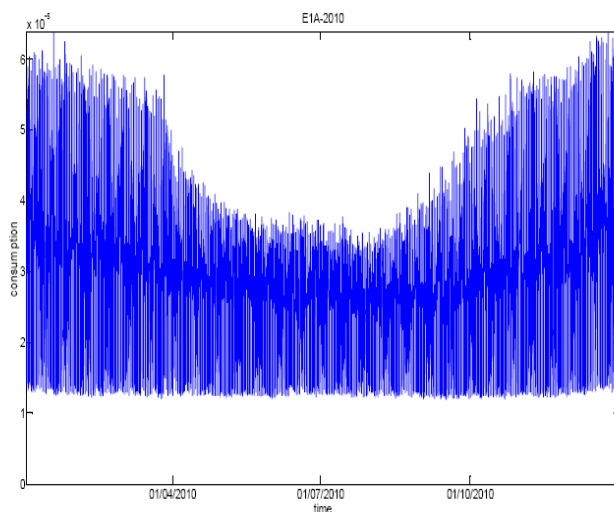


Figure 29: EDSN Electricity use profile E1a for 2010. (EDSN, 2009)

For electricity there are two variables that differentiate the records. There are connections that are annually invoiced and there are connections that are invoiced every month. Additionally there are connections that have a standard tariff and connections that have a split peak and dip tariff.

***Annually invoiced E-connections:***

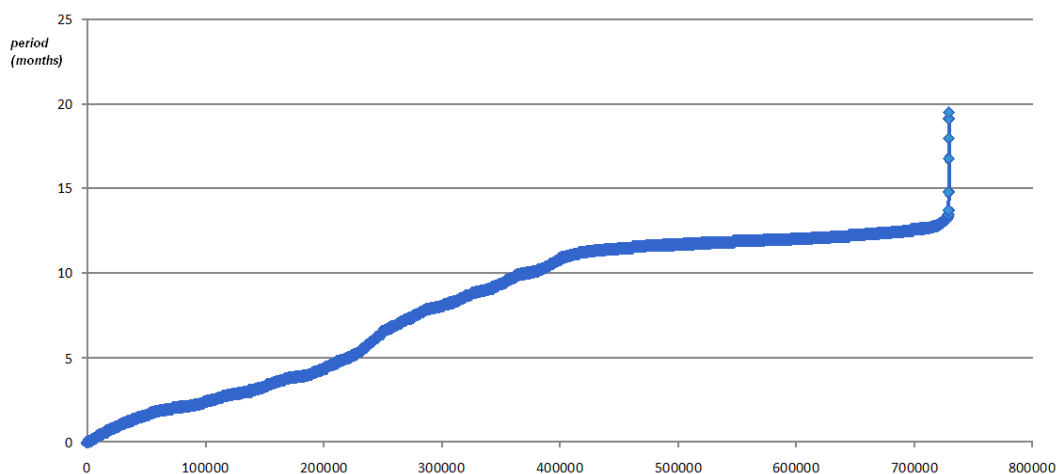
The records of this dataset are entered into SAP as they come in. For existing connections the first record starts somewhere in 2004-2005. Most active connections have an end date of the last time period sometime in 2009. The connections that are invoiced in a double tariff have two records for the same period, both containing either the peak or the dip use. These were then aggregated so the total use was represented in the remaining records.

Preferably the total use over the total recorded period is divided by the time it spans. This would result in the exact principle form of the average annual use over the period 04-09. This only works for periods that span a period that is made up of entire years. The connection's records were therefore first aggregated and the total period analysed. Any total period that was between 0,95 and 1,05 year(s) was identified. The representative annual use for these connection was determined by dividing the total use of the period by the actual fraction of years the period spanned.

The remaining connections were scanned for single records that spanned an entire year. For the connections for which such a record existed the used value of this single record was taken as representative value. It is known that the total electricity use in Eindhoven grows by 2,5% annually while the number of connections grows by between 0 and 2% annually as well. This means that the total inaccuracy introduced per connection handled this way is expected to be between 0 and 2% while it is certainly between 0 and 5%.

The connections that were still without a representative value were analysed for a number of variables. The average use, time period, zip code distribution and ID numbers were all found to be resemble the entire population. For this rest group the representative value was then determined by dividing the total recorded use by the total record period. This decision should not affect the accuracy of the represented total use in Eindhoven though it does affect the expected accuracy of these individual connections.

The final check performed was on inactive connections. The period spanned by individual connections was analysed. This showed that when no records had been entered for a connection for over 14 months it was likely to be inactive. (Figure 30) This was visually checked against the connection status derived from a SAP dump from a later period and this seemed to imply this method of determining inactivity was accurate. The status from the SAP dump did not match the data so a superficial check was all it could be used for.





	Number of connections
Total connections E (annually invoiced)	105.652
Inactive	1.812
Active (period in entire years)	60.935
Active (Single 1 year period)	36.802
Active (rest)	6.103

*Table 18: annually invoiced connection statistics*

### **Monthly invoiced E-connections:**

There is a total of 1468 active connections that are invoiced every month in the Eindhoven area. The connections that are invoiced in a double tariff have two records for the same period, both containing either the peak or the dip use. These were then aggregated so the total use was represented in the remaining records.

The periods represented in the records are not always in entire months. The periods were therefore put in chronological order and numbered starting at the oldest. The period spanned between the first recorded date for a connection and every connection record's end date were determined. The periods within 5% of a whole year were isolated and the longest period per connection taken. The total use was then divided by actual period the records spanned. It resulted in the representative value of these connections. This worked for over 1350 connections, the total periods ranging from 12 to 48 records.

For the remaining connections the total use was divided by the actual period spanned in days. These were generally the new connections that were activated in 2009. The same considerations apply as did in the previous subsection.

	Number of connections
Total connections E (monthly invoiced)	1528
Inactive	60
Active	1468

*Table 19: monthly invoiced connection statistics*



## Appendix 3: Summary

### SMART GRIDS IN EINDHOVEN: AN EXPLORATION

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**Date of graduation:**

26-08-2010

#### ABSTRACT

*The energy sector is undergoing some fundamental changes. The implications of smart grid technology for electricity grids is as yet unknown. This paper presents the results of a graduation research project exploring developments in smart grids carried out at Endinet. A general exploration constitutes the first phase of the project. It entails a broad study of all aspects of smart grids. Based on the insights gained during this exploration, possible implications for the expected future development of the Eindhoven electricity demand are researched. This is done through the development of a realistic worst-case scenario for electricity demand for Eindhoven in 2040. Using the results from this scenario an estimate of the investments needed in the network to maintain operational quality at the current level under the 2040 scenario loads is drawn up.*

**Keywords:** Smart grid, scenario, electricity use, electricity peak load, required investment

#### INTRODUCTION

Both Endinet and the KENWIB are in the early stages of exploring smart grids. Since the field is broad and the technologies and market developments involved in smart grids are multiple it is important to explore the scope of developments and identify which might be relevant for Eindhoven. For Endinet it is relevant to create an understanding of the implications these developments might have in terms of investments and network operation.

It is to be expected that the energy sector will undergo some fundamental changes in the near future. These might include electric cars, heat distribution networks, decentralised generators, sustainable intermittent generators and 'smart' technology. International agreements on sustainability as well as economic and political considerations will help these changes to come about. Network operators like Endinet are at the core of these changes. What these changes entail, what they could mean for Eindhoven and the implications it could have for Endinet are as yet unknown.

**Goals**

The first goal is to generate insight into the future requirements of the electricity network in Eindhoven. The ability to consider the entire lifespan of components will allow for more efficient and more economical and sustainable choices. The developments in electricity network technology are multiple and there is as yet little knowledge about their potential relevance to the Eindhoven region. The project serves to broaden the planning horizon of Endinet's asset management by generating insight into future requirements. This will allow for more economical and sustainable investment decisions.

The second goal is to explore the developments in the field of smart grids and generate insight into the potential consequences for stakeholders in Eindhoven, in order to initiate and stimulate an open multilateral discussion about developing the future energy system of Eindhoven. It would be beneficial to the process of achieving 'Eindhoven energy neutral by 2045' if there were to be a societal discussion about the future of energy supply and use in Eindhoven. This discussion should focus on achieving an integrated sustainable energy strategy. Endinet wishes to contribute to this discussion by supplying its knowledge and experience in operating energy networks. In this role it is paramount that there is a familiarity with current vision and policy, the associated scenarios for future use of energy systems and developments in all aspects of the field of 'smart grids'.

**Research questions**

Research question 1:

*What aspects and developments of energy networks are described by the term 'smart grids', what are the current developments in this field and what future developments might be expected?*

Research question 2:

*What would be a worst case scenario for the electricity consumption and expected load for Eindhoven's electricity distribution grid by the year 2040?*

Research question 3:

*In a worst case scenario, what will be the investment needed to meet the requirements for Eindhoven's electricity distribution grid by means of conventional technologies and methods?*

**Project design**

The first stage of this project comprises an exploratory study of smart grids and new developments in this field. The current status of smart grid development is explored. In order to predict the transition path towards smart grids and the current sector, its stakeholders, organization and technical status are described and subsequently analyzed using Multi Level Perspective (MLP) as a framework. The main level of MLP is the level of socio-technical regimes. This level includes the current state of technologies and social 'rules' that form a dynamically stable situation. At this level it is not possible to explain radical change to regimes. In order to explain this the 'niche' and 'landscape' levels were introduced. The Niche level is a micro level in which radical new technologies emerge. The socio technical landscape form the surroundings in which a socio-technical regime and a number of niches might exist. Pressure from certain landscape changes can make decisions on regime level easier or more difficult. Though niche level developments are a prerequisite for transitions of the regime they are not always a sufficient condition to see the transition

through. The best chance for a transition to take place is when niche developments coincide with landscape pressures pushing the regime. (Geels, 2002)

The second part of this study will investigate the future challenges faced by networks and their consequences when faced without the aid of smart technology. Based on the results and insights gained in the exploratory study a realistic worst-case scenario for Eindhoven is developed.

The final part of this project results in an estimation of the investments needed in the electricity grid in Eindhoven to cope with the scenario loads. This estimation is generated using indicator numbers on network redundancy and component prices. There are two factors that are important to future grid development. These are peak loads and decentralised generation capacity. Given the importance of peak capacity to dimensioning the grid this scenario will focus predicting the future load profile.

### EXPLORATION OF THE TERM SMART GRIDS

By studying literature and interviews with people active in the electricity sector an overview of smart grid developments and the current status of the electricity sector is created. This overview includes current stakeholders, regulations, technical aspects, infrastructure and infrastructure at the socio- technical regime level, pressures on regime from the landscape level and a description of niche developments. This overview is used to identify the most likely transition pathway and the characteristics of the socio-technical regime in its end state.

#### Definitions of smart grids

There are a lot of interpretations of the term smart grid. There is no consensus about the exact definition of a smart grid. To be able to understand the different meanings and definitions it is important to consider who is using the term and in which context it is being used. There are three types of definitions that are being used to define a 'smart grid'. Problem based definitions are based on the textual context in which the term is being used. Standard definitions are objective, unbiased and generally applicable definition. The third and final type of definition are based on a time and location specific context resulting in a demarcating definition that defines the smart grid as it is applicable to that specific context. The definition proposed by the European Regulators' Group for Electricity and Gas (ERGEG) is the most defined definition that is generally applicable for the Dutch context.

*"Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety." (ERGEG, 2009)*

The definition reflects the level of demarcation that applies to the term given the current state of development in the Netherlands. At this time this demarcation level is also suitable for Eindhoven since the future of the Eindhoven energy systems has not been further defined than the national systems have.

#### Functionalities attributed to smart grids

Even though there is no consensus about what a smart grid should exactly be, there is a number of functionalities that are generally attributed to smart power grids. There is an

almost endless list of possibilities and the goals set will eventually determine which functionalities will be realized.

Most stakeholders directly involved with networks, including ERGEG and NBNL, consider smart grids solutions to apply measures that allow for increased intelligence for planning, operating and maintaining networks. Even though these three tasks in a network life span are very different the smartness always starts with information. Nearly every functionality described as part of a smart grid starts with having more accurate, often real time information about network and component performance. The smartness of the network then lies in utilizing the available information to a certain goal.

Smart metering is a development that is often associated with smart grids. Often confused with smart grids it is important to realize that smart metering in itself does not constitute a smart grid. Only when the information provided by smart meters is used to provide functionalities like demand management/powermatching will the grid become a smart grid. Figure 3

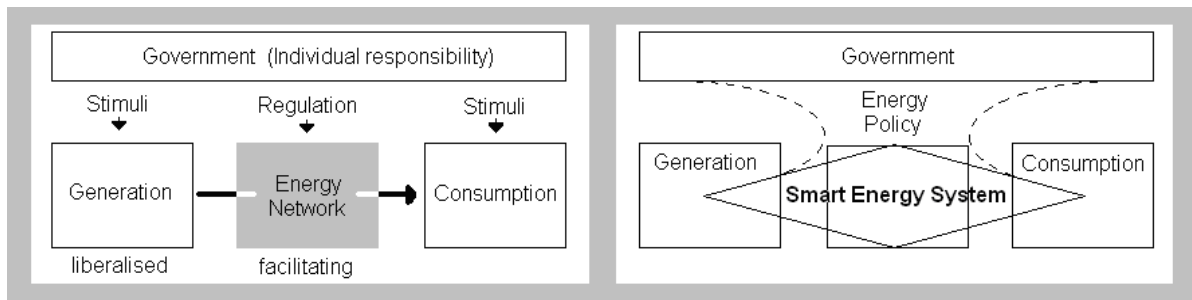
### **Transition pathway towards smart grids**

At first glance the electricity sector is in a suitable state for technological transition to take place. There is tension and dynamism in the regime, there are strong and concrete landscape pressures and a number of niche developments have taken place. Public infrastructural regimes are by nature of great stability and possess great inherent resistance to change. This resistance is mainly caused by the high economic value of current infrastructure and conservative regulation. There is however a lot of tension and dynamism in the current regime due to recent unbundling and privatization.

On the landscape level there are forces pushing for change in the energy sector. The social and political willingness to achieve energy transition is there though it hasn't been translated to actual commitment yet. Both the dependency on a limited number of countries with often politically unstable or inconvenient regimes as the need to improve environmental sustainability are strong factors empowering the drive for energy transition. In the niche level several technological and market developments have spawned and have proven to be ready for penetrating the current socio-technical regime.

Until a structured societal approach to energy is adopted, the development of energy networks remains reactive and a pro-active development of 'smart' networks will be near impossible. The government is looking at the free market to take up the challenge to provide energy transition through innovation and development. Keeping those parts of the sector in public ownership that are critical to ensuring quality and safety of energy supply. This approach presents two problems to the development of smart grids.

Primarily the unbundling isolates innovations in either generation or consumption making system integration more difficult. This prevents the sector from being totally reformed, limiting developments to adjustments and localized innovation within the existing system. Secondly the regulation, and the interests it protects, restricts the ability of the networks to pro-actively participate in innovations. Current regulation promotes passive network operators that reactively facilitate the market. The regulators focus on the existing interests and lack of motivation to incorporate other public interests in regulation makes it very unlikely network operators will instigate change without public consensus.



**Figure 1:** Current situation energy sector; Alternative suited for achieving sustainability

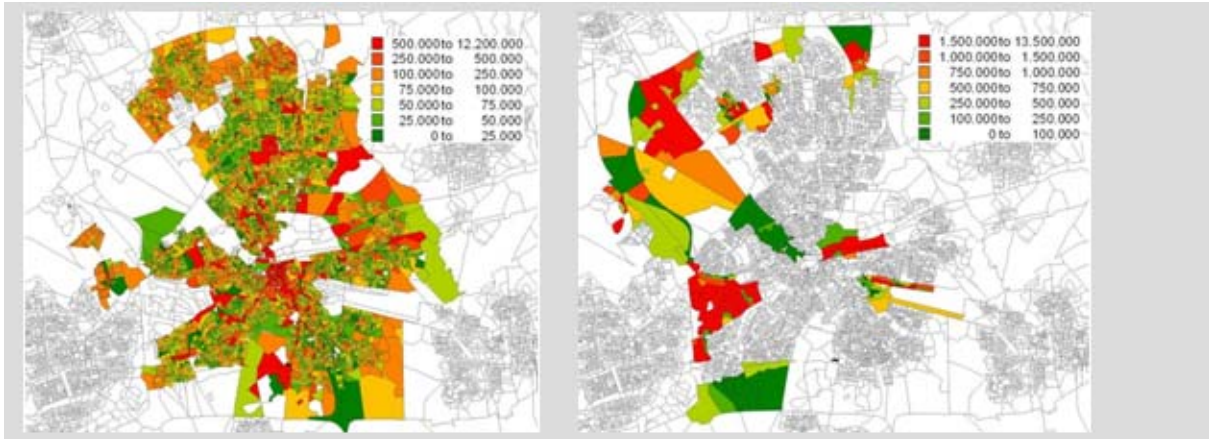
Based on the current state of all three MLP levels it seems a Hybrid grid is the most likely future for the Dutch electricity network. This hybrid grid will include both central and decentralized generation and will utilize smart technologies to let both types of generation as well as active demand to contribute to balancing supply and demand. This hybrid grid type will not require major rebuilds of the existing electricity networks but can be realized by 'smart' replacements during routine maintenance and adding of smart components like smart meters. The transition process associated with hybrid grids will allow the current stakeholders to remain the key players.

#### REALISTIC WORST CASE SCENARIO FOR EINDHOVEN'S ELECTRICITY GRID

The goal of the scenario is to generate an idea of what maximum investment could lie ahead for Endinet. The scenario developed should be a worst-case scenario seen from the perspective of the electricity grid in Eindhoven.

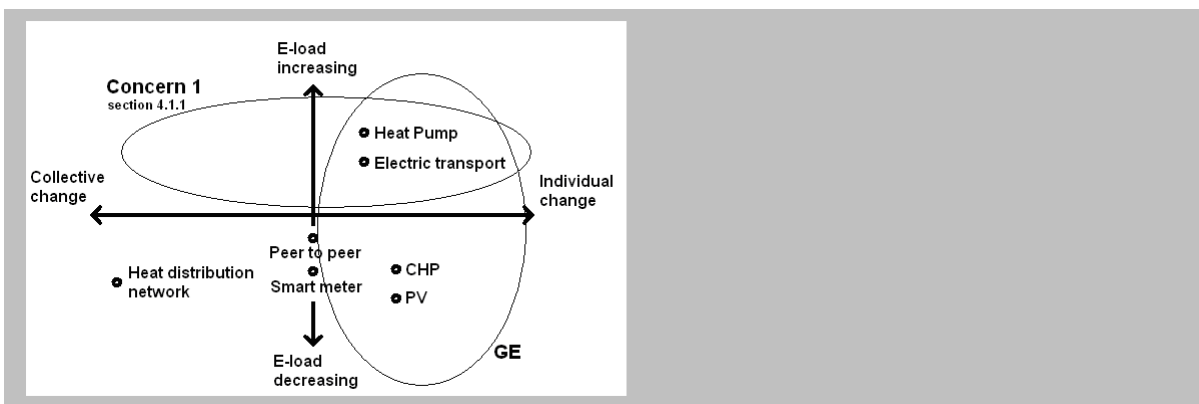
For Eindhoven, being an urban environment, it is expected that peak loads in the network constitute the main problem. (Laborelec, 2009) The availability of small scale DG in urban areas on a LV level is expected to stay a niche as long as an individualist approach to reshaping the energy system is chosen. It was therefore decided to develop a scenario in which all changes in the socio-technical regime are adversely influencing the worst case aspect 'maximum peak loads' on the network. The socio-economic framework for the scenario is based on CPB's Global Economy scenario since this presents the economic growth and individual orientation provide the highest potential for peak loads.

In projecting the future peak loads two components are separately determined. The basic electricity use is determined based on the current electricity use, EDSN standard load profiles for different connection capacities and an extrapolation factor. The current representative electricity use per connection is determined through analysing the invoicing data from Endinet from between 2004 and 2010. The results from this analysis are shown in figure 2. The extrapolation factor was based on projections from ECN and Telos that were also based on CPB's Global Economy scenario.



**Figure 2:** Annual electricity use Eindhoven 2009 (kWh)- (household/services ; industry)

New technologies have their specific characteristics and subsequent consequences for the total energy use, electricity use, load profiles and reactive power components. When technologies are introduced on a large scale, changing the characteristics of the current socio-technical regime these specific characteristics will have consequences for the capacity and design of the energy distribution networks. From all new developments the developments were chosen that meet two criteria, they should fit the individualistic nature of the Global Economy scenario and they should adversely affect the maximum electricity load on the network. The technologies that were identified to meet these criteria were Electrical transport and Heat pumps. (figure 3)



**Figure 3:** Technologies relevant to electricity peak load-worst case scenario

Table 1 shows the resulting values for the different elements and total worst case scenario developed.



		Domestic	Domestic double tariff	Services	Domestic double tariff	Industry
Nr. of connections		91,713	8,664	2,736	906	1,289
Extrapolation factor		1.42	1.42	1.68	1.68	1.62
Extrapolated peak load	kW	1.12	1.77	7.09	13.11	121.54
Electrical transport	kW	0.25	0.25	0.25	0.25	
Heat pumps	kW	4.55	4.55			
Total scenario loads per connection category:						
Average peak load	kW	5.92	6.57	7.34	13.36	121.54
Total peak load	kW	542,835	56,934	20,069	12,105	156,054

**Table 1:** Peak loads scenario 2040 per connection type

**Total peak load Eindhoven 2010:** **199 MW**

**Total peak load worst case scenario Eindhoven 2040:** **788 MW**

### PROJECTED TRANSITION INVESTMENT

To estimate the investments for facilitating the projected peak demand through traditional means four aspects are important. These are the current network capacity, network load compared to maximum capacity, the scenario peak loads determined in the previous section and the price of network components at all network levels.

At 7 levels in the electricity network the number of components and their average capacity is determined. At each level the 'n-1' redundancy criterion is used in the Eindhoven network. This means that at all levels and at all times a critical component may fail without the network capacity dropping beneath the peak requirements. In this calculation this is accounted for by reducing the real number of components by the number of cables, sections or cable routes at each level. The capacity was calculated using the following formula:

$$P_{(n-1)} = N_{(n-1)} * U \text{ (V)} * I \text{ (Amp)} * \sqrt{3} * \cos \phi = \text{max. Capacity (MW)}$$

In which:  $N_{n-1}$  = Number of components (n-1);  $U$  = Voltage level (MV= 10 kV; LV= 400V);  
 $I$  = average component capacity (Amp);  $\cos \phi$  = factor representing the difference between real (energy used) and apparent (energy transported) power

For the extrapolated basic use and EV it is assumed that consumer behavior stays the same as it is in 2009. This means that the spread in usages at peak time and the concurrency of these loads remains the same. With these conditions remaining the same it is wise to maintain the same redundancy, and thus utilization percentage, to be sure that the network can cope with local variances. Utilization percentages range from 12% (LV level) to 76% (main distribution stations)

The heat pumps are assumed to be 100% concurrent loads, every heat pump operating at full capacity during extreme winter weather. For the average load the distribution of the load over the connections is identical every time because all pumps are at maximum capacity per connection. With predictability being higher for this type of load the network redundancy can be allowed to drop with respect to these loads. Currently the higher

network levels reach a utilization percentage of up to 76% so it is assumed the Eindhoven network can cope with this percentage. Using the component of the peak load that requires the current utilization percentage and the heat pump load that is allowed 76% a permitted average load percentage is calculated for every level. From this the required network expansion is calculated. This expansion factor is then multiplied by the value of the current network based on 2009 component prices.

Network level	Worst case scenario 2040 (Basic use, EV and heat pumps)				
	Projected max load	Permitted load %	Required network capacity	Required expansion factor	Estimated required investment
Purchase stations				3.51	€ 10,000,000
Main feeder cables	774 MW	76%	1,017 MW	3.51	€ 45,000,000
Main distribution stations	774 MW	76%	1,017 MW	4.08	€ 45,000,000
Transport cables	756 MW	63%	1,190 MW	3.39	€ 40,000,000
District distribution stations	756 MW	69%	1,102 MW	3.69	€ 45,000,000
MV ring	756 MW	62%	1,227 MW	3.28	€ 105,000,000
Transformer stations	756 MW	55%	1,369 MW	2.99	€ 140,000,000
LV network	756 MW	24%	3,162 MW	2.07	€ 90,000,000
<b>Total required investment</b>					<b>€ 500,000,000</b>
<b>Cost per connection</b>					<b>€ 5000</b>

**Table 2:** required investment estimate worst case scenario 2040

## CONCLUSIONS

The exploration of smart grids and the current electricity sector with regards to a 'smart' transition resulted in the following bullet point conclusions.

- There is no consensus about the exact specifications of a smart grid
- The public sector needs to define a direction for the energy sector and direct or guide developments
- Landscape pressures and Niche developments are available to trigger a technological transition in the sector
- There is an inherent resistance against transition but also a lot of tension and dynamism that favor transition within the current socio-technical regime
- A Hybrid grid adding 'smart' elements to existing grids and combining central and distributed generation is the most likely future for the Dutch electricity network

In developing the realistic worst case scenario it was shown that there can be several types of worst case scenario for electricity grids. Maximum peak loads and distributed generation capacity are both potential worst case aspects. The scenario developed addresses the maximum peak load aspect. In a scenario based on economical growth and an accent on individual responsibility, heat pumps and electrical vehicles are identified to be developing technologies that present the biggest threat to increase peak loads.

Based on scenarios by CPB, ECN, Ecofys and Telos the total annual electricity use in Eindhoven was shown to increase by 80-100% from 1.0 billion in 2010 to approximately 1.9 billion kWh in 2040 according to this scenario. The increase in peak load will be even more profound rising 280% from 199 to 790 MVA. This shows that in this scenario the maximum

load flow increases more than the average load on the network. This means the average network utilization over the year will also decrease even further.

The investment needed to facilitate the realistic worst case scenario developed is € 500 million. This number is not corrected for inflation and would have to be invested in the thirty year period between 2010 and 2040. The estimate is based on facilitating the scenario using only the traditional network, without the benefits of new technologies like distributed generation or smart functionalities like active demand. Over 80% of the total required investment has to be invested in the MV network levels, only 20% in the LV network. The total required investment would mean a € 5000 investment per connection.

## DISCUSSION

Due to the fact that energy carriers are often interchangeable, It has however been proven to be very hard to accurately predict future developments for individual networks. Only when the choice of energy carrier for specific purposes can be predicted can accurate projections for individual networks be generated.

This project focussed on the future of the electricity network. Considering the difficulty in projecting future requirements for individual energy networks when the balance between the energy networks is not yet decided it was decided to create a lower and upper limit to the range of possible future requirements. This project aimed to provide the upper limit for the electricity network requirements (research question 2) and the investment that would then be needed. (research question 3) The scenario developed only addresses the impact of increased peak loads on the network. It discarded the potential risk distributed generation poses to network operations. The aspects on which a worst case scenario can be modelled do affect each other. Even though their relation was not researched it stands to reason that both scenarios will positively affect the impact of the effects of the individual scenarios. It is therefore important to realize that the projected result is also the upper limit, the maximum investment requirement, not the 'expected' investment requirement.

The projected required investment is specific to Eindhoven. Whereas the general scenario is based on national projections and therefore valid for most urban areas in the Netherlands the cost estimate is not. Network philosophy, design, operational procedures and prices on which the projection is based are specific to Endinet's networks. It would thus be unwise to simply assume the projected investment requirement to be valid for other urban areas.

It seems that changes in time, place and form of electricity demand and supply have potential consequences for energy networks and systems. Smart solutions are as yet optional and thus represent opportunities to cope with developments by reducing the impact of consequences these changes have. Obviously choosing to implement smart elements will have consequences of its own but at this point I feel that because 'smart' is still optional it represents opportunities rather than said consequences.

Increasing sustainability and security of energy supply is the main driver for energy transition. It seems that based on the existing drivers sufficient motivation is generated to keep discussions going. Eventually economic aspects come into play when changes need to be realized. Currently the costs for transition are considered very high resulting in a significant barrier for actual commitment to realizing change. Low energy prices are often blamed for the high perceived cost associated with energy transition. The cost estimate

developed in this project shows that significant investments might be needed even when no smart investments are realised. In actuality smart grids might contribute to reducing the total costs of changing the energy system. I hope this long term investment projection will eventually contribute to an integrated approach of evaluating the economic implications of changes to the entire energy system, including (smart) grid development.

## RECOMMENDATIONS

The results from this project have answered the research questions posed but both within the scope of these research questions as in the scope of the goals some aspects were not (fully) included. Additionally the process and results present new insights and these give rise to new questions to be researched.

With respect to generating insight into future requirements this project has also generated insight into the current operation of the electricity network. An indicator number based method has been generated providing insight into utilization factors at different network levels. The representative annual usage analysis creates insight into current electricity use distribution. The possibility of matching this usage data to both network sections as well as other postal code based databases can in future provide insight into consumer behaviour and contribute to accurately predicting load profiles throughout the network. Further research into energy use and possible correlations with other databases containing demographical data can establish more reliable or specific indicators for energy use.

This project has established an upper limit for required investments by establishing a cost estimate for a realistic worst case scenario. This project discarded the risk distributed generation poses to Electricity networks. I would recommend developing this scenario and estimating the associated network investments needed.

The interchangeability of energy networks make that for decisions on the electricity network to be made similar insight into other networks will be needed. Research into the possibilities, implications and required investments of other options is therefore needed. Hydrogen cars, heat distribution, biogas are amongst the alternatives available. Especially the possibilities of heat distribution networks is not yet fully known in the Netherlands. It is recommendable that we learn from experience abroad with unfamiliar network types.

Further research will then be needed to not only show limits but also differentiate the costs associated with all variables that make up realistic scenarios. Only then can a proper decision on the future energy system for Eindhoven be made considering all technological options and based on all interests including security, sustainability and economic aspects.

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This graduation project at Endinet was a project combining the technical background of my Bachelor Building, Architecture and Planning with the managerial aspects of the Master Construction Management and Engineering. The enthusiasm and involvement from colleagues at Endinet for achieving a sustainable and secure future energy network for Eindhoven greatly contributed to the final result. I sincerely hope this project will contribute to achieving the KENWIB goals.

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