To Store or Not to Store

A Q-Methodological Study into the Influence of Perceived Needs and Factors on the Implementation of Electrical Storage Applications in the Dutch Power Grid

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Abstract

Modern society is highly dependent on the reliable supply of affordable electricity. To ensure a sustainable future, this energy should be derived from renewable generation systems. The intermittent output of such systems makes it hard to maintain the so-called grid balance, which can lead to the malfunctioning of the current power grid. Adding electrical storage applications to the electrical energy infrastructure is increasingly mentioned as a viable and even instrumental solution, but no stakeholder seems willing to act. This research combines PESTLE analysis with Q-methodology to investigate and describe the variables that influence this situation. In doing so, it lists the institutional factors that are presently deemed by various stakeholders to be either opportunities or barriers to implementing a system to maintain grid balance in the Dutch electrical infrastructure. A tentative conceptual modal is proposed to illustrate the mutual influence of the perceived external forces that could induce change in the Dutch electricity sector.

Acknowledgements

In February 2017, after 12.5 years of service in the Royal Dutch Navy, I was given the opportunity to go back to university in order to get my engineering degree. A lot has happened since then.

My family has moved houses... Twice. I changed jobs… Twice. My wife changed jobs… Twice. And most important of all: My wife and I became parents… Twice.

The submission of this thesis marks the completion of my studies, thereby ending a busy period for my family and myself. I am convinced that before long we will engage in new challenges.

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Last, but absolutely not least, my wife Maaike. It has not been easy, for neither of us. You are awesome. I will keep my promise by treating you to a nice breakfast with a view of Big Ben. How about a small break before you start your master's degree?

Finally, I would like to express my love to the two people who made my study, and especially the final thesis, extra challenging, but simultaneously motivate me to continuously develop myself: My little big girl Lauren and my big little girl Noémie. Please, never stop smiling and never cease exploring.

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1. Introduction

'*The (Dutch) Power Grid cannot cope with local generation of electricity. The capacity of the power network is the bottleneck for the energy transition*' (van der Berg, 2019).

'The transport of electricity is now the bottleneck for the development of the German energy-wende' (van de Poll, 2019).

These are only two of the many references in recent newspaper articles to looming complications for the electrical energy infrastructure. Although energy transition has been an increasingly importance topic of discussion for decades, the focus has long been on the need to replace fossil energy sources with sustainable, renewable alternatives. Now, the discussion is broadening to include the energy infrastructure as an equally important issue.

The crux of the problem lies in continuously maintaining the so-called net balance of the power grid, which Koç (2015, pp. 11–12) defines as the '*perfect balance between supply (production) and demand (use) of electricity*'. Koç explains that the power grid is the physical intermediary between this supply and demand. As such, the balance between the two needs to be maintained at all times. This requires adjusting on a nano- to millisecond scale in order to manage and enable the transportation and distribution of electricity.

The current power grid was designed and built based on centrally located and controllable fossil fuelled power stations. However, many renewable electricity sources are decentralised and non-controllable. As such, maintaining the net balance becomes increasingly complicated (Bongaerts, 2018; van de Poll, 2019; van der Stelt et al., 2018). According to Koç (2015), failing to control the balance in any part of the power grid could lead to cascading failures spreading through the entire infrastructure. The growing attention for the quality and robustness of the grid is therefore justified.

This thesis investigates the anticipated challenges in maintaining the net balance on the Dutch power grid. The emphasis of the research is on the perspectives of experts with regard to the implementation of storage applications as a solution to said challenges. These expert viewpoints are important in the decision-making process for the implementation of a viable balancing mechanism in the power grid.

This thesis and its research are exploratory in nature. The outcomes should be considered as tentative and open to further exploration. Next, the problem at hand is described in greater detail.

1.1 Societal Developments Influencing the Grid Balance

The challenge of maintaining the net balance in the power grid is in large part caused by three major trends.

Increasing Worldwide Energy Consumption

Between 1973 and 1998, the world usage of energy increased by 57% (Evans, Strezov, & Evans, 2012). Dell & Rand predicted another increase of 40% between 1998 and 2018 (2001). In hindsight, the actual increase in this timeframe was 68%. Furthermore, the current estimates show a further acceleration in consumption (*World Energy Consumption Statistics | Enerdata*, n.d.).

Electrification of the Energy Sector

As a further complication, the transportation of energy to the end-users is increasingly done by means of electricity instead of other forms like oil and gas. According to the International Energy agency and the European Commission, the relative share of electrons (electricity) in the usage of energy is estimated to increase from 20% (2017) to 40% before 2050 (Hoogma, 2017). This is in accordance with the findings of TenneT, the Dutch Electrical *Transmission System Operator* (TSO). They observed an increase in the share of electrons in the Dutch energy mix from 16% (2006) to 21% (April 2018). TenneT expects this share to rise to 40-45%. They predict a 50% share of electrons to be the maximum a modern power grid can handle (van der Meijden, 2017).

Integration of Renewable Electricity Production

During the International Climate Summit in Paris (in 2015), 179 nations and the European Union (as of August 2018) recognized the need to reduce the emission of Carbon Dioxide. This to prevent the earth's average temperature from rising 2 degrees Celsius compared to 1990 (*ADOPTION OF THE PARIS AGREEMENT. Proposal by the President*, 2015). The energy sector relies for 80% on fossil fuels, and the use of fossil fuels accounts for 80% of the world carbon dioxide emission (Johansson & Turkenburg, 2004) Consequently, the Paris climate agreement acknowledged the necessity to change towards *renewable energy production*. Renewable energy production is defined *as "an energy resource that is replaceable by a natural process in such a way that its energy usage does not lead to its depletion.*" (*ADOPTION OF THE PARIS AGREEMENT. Proposal by the President.*, 2015, p. 2).

Renewable production sites are decentralized. This means they are often built outside the original power grids. '*This negatively affects grids in terms of regional overloading of transmission lines*' (Koç, 2015, p. 3). This leads to '*reduction of available tie-line capacities, frequency performance, grid congestion, increasing need for power and reserve capacity and increasing power system losses*' (2015b, p. 4).
In contrast to fossil generated electricity, renewable electricity generation is uncontrollable due to its dependence on the prevailing weather conditions. The generation of electricity is variable, intermittent and discontinuous in nature. Therefore, the frequency and output of the electricity is not stable. This leads to a variable demand of the power lines which causes wear (Dell & Rand, 2001; Johansson & Turkenburg, 2004; Vazquez et al., 2010). The integration of *Renewable Electricity Systems (RES)* is not the sole cause of balancing challenges. Their integration in the power grid does however accelerate the need to deal with these challenges. This was already observed and acknowledged prior to the ratification of the Paris Climate Summit. (Mohanpurkar et al., 2017; "*World Energy Consumption Statistics | Enerdata*", n.d.).

The call to effectively transit to *RES,* as depicted in the Paris Agreements, demonstrates the need to increase the flexibility of the power grid. The use of storage applications for electricity is increasingly mentioned to achieve this. This is championed by Gottwalt et al. (2011, p. 8163): '*The existing power grid is designed to distribute electricity from few large, constantly generating power plants. Hence, the increasing share of renewable energy resources, which are decentralized, small units with variable capacity, conflicts with the current power grid control infrastructure. A reliable electricity supply in a grid with a large share of volatile generators can only be guaranteed with adequate balancing reserves resulting in high investments for storage.'* Currently, power operators and network managers choose to curtail renewable resources during times of oversupply and unfavourable market conditions (Barnhart et al., 2013, p. 2804; González et al., 2004, p. 472; Jorgensen & Ropenus, 2008, p. 5335,5336; Mohanpurkar et al., 2017, p. 1; van de Poll, 2019; van der Berg, 2019).

1.2 The Role of Electrical Storage Applications as Balancing Mechanisms

The idea behind the implementation of storage applications in the power grid is their ability to decouple electricity generation from its demand, both in terms of time and space (Dunn et al., 2011; Vazquez et al., 2010). Consequently, it can enable the supply of electricity with the required *power quality* characteristics to the grid, regardless of the location and the intermittency of its generation.

The decoupling of supply and demand of electricity in terms of time facilitates the safeguarding of the *equality constraint*. This is the need to continuously ensure that the electrical energy fed to the grid equals the sum of its demand and the losses suffered during its distribution. It also reduces the risks of overloading the power lines, as it enables to postpone the transportation to times of lower grid demand.
The decoupling in terms of space allows the transportation of electrical energy for local regeneration. It also enables the usage of alternative means of transmission and distribution, thus decreasing the load on the power lines.

In view of the anticipated benefits attributed to such systems, it is interesting investigate why they are not implemented in the supply chain of electricity.

1.3 The Research Gap

This thesis investigates the role of electrical storage applications in the development of the power grid to enable a *sustainable energy system,* without compromising on its *robustness.* The development of such a system defines the *ideal end-state* of this research.

A *sustainable energy system* is defined as a system that enables economic growth and energy security, while providing *environmental protection*. *Environmental protection* is achieved when society is protected from the associated harmful emissions and consequent climate change (Dell & Rand, 2001). The r*obustness* of a system is defined by Koç as *'the ability of a system to avoid malfunctioning when a fraction of its elements fails as a result of deliberate attacks or random failures that limit the ability of the system to accomplish its tasks. '*(2015, p. 18).

There have been hundreds pilot projects to implement storage applications in the power grid in the Netherlands alone. However, their implementation remain a topic of discussion with notorious proponents and opponents. ("*Met gas naar een klimaatneutraal energiesysteem—Innovatie en Kennisagenda Gas 2016—2019*", 2015).
According to Weeda and Gigler (2018), this is not solely due to technological factors. The associated *institutional factors* are equally important. These factors are defined as the full range of opportunities, regulations and business models that steers the way in which technologies and processes are embedded in and accepted by society.

The knowledge gap investigated in this research is thus the presence and composition of these *institutional factors* and their consequences in the decision-making process of implementing electricity storage.

1.4 The Research Scope and its Justification

The research scope of this thesis is limited to the perceptions of various *stakeholders* and *outsiders* on the implementation of storage applications in the *Dutch* power grid.

A *stakeholder* is defined as an actor involved in, affected by, or having relevant expertise in the issue at stake. An *outsider* is considered a stakeholder who has an alternative vision on the functioning of a sector but is currently not sufficiently involved or influential.

To date, most countries do not structurally include any form of storage systems in their electrical infrastructure. As a result: '*at present, the electric power infrastructure still largely functions as a just-in-time inventory system in which a majority of energy is generated and transmitted to the user as it is consumed. Electric power generation is continuously ramped up and down to maintain the net balance between supply and demand, resulting in higher fuel consumptions and emissions per kWh produced, and causing wear on the equipment.'* (Dunn et al., 2011, p. 929).

A research conducted in 2013 estimated that the capability of the Dutch power grid to support the integration of more than 4 GW of renewable electricity production to be questionable. At the time, this was 7.3% of the national electricity supply (de Boer et al., 2014). This is considered to be the *actual state* of the infrastructure. Although current numbers will differ, recent reports confirm the requirements for further developments of the grid (Hoogma, 2017; Weeda & Gigler, 2018). It justifies the Dutch scope, as its government ratified the Paris climate agreement. As previously deducted, this calls for the need to implement viable balancing mechanisms.

Innovations in the Dutch energy sector are usually delayed or even cancel because of non-technical issues. Historically, applicable developments, investments, policies and regulations were technology-pushed to accommodate the prevailing working operation of Dutch industry and economy. This hampers the introduction of radical innovations. Workgroups and advisory boards are often led by dominant stakeholders. Furthermore, the policies with regard to the topics of energy and environmental protection are not mutually consistent. This has economical and societal consequences (Kern & Smith, 2008; Verbong & Geels, 2007; Weeda & Gigler, 2018). This justifies the focus on institutional factors and the inclusion of both stakeholders and outsiders.

1.5 Research Relevance

The research relevance is discussed assuming the pursuit of the *ideal end-state* versus the *actual state* of the Dutch power grid.

Practical Relevance

The consequences of a malfunction in the Dutch power grid were shown on September 27, 2015. A power failure occurred in the province of Noord-Holland and Flevoland. This left over a million household without electricity. It disrupted the traffic safety, hospitals, as well as the activities of companies. The outage lasted only an hour, but it lead to damages of up to 4 billion euros (Diekman, 2017).
In May 2018, the *Dutch Data Centre Association* (DDA) emphasized the need to guarantee the reliable supply of electricity to datacentres. This was done because the local power grid was not expected to accommodate their extension. This is instrumental for the national economy, since companies are increasingly dependent on the use of web-based applications (van Heerde, 2018).

A Danish study by Lund and Münster (2003) discusses various strategies for grid operators to deal with the balancing challenges. This includes the limitation of renewable electricity generation sites and the curtailment of current renewable electricity production. Alternatively, they mention the enforcement and expansion of high-voltage transmission lines. Finally, they suggest implementing a flexible and viable balancing mechanism through the implementation of storage. This is expected to be the best solution from a point of view of technology, costs and sustainability.

The decision of how to invest in the power grid involve considerable costs and '*will determine the structure and capacity of the energy system for decades*' (Kern & Smith, 2008, p. 4101). The decision-making process is, therefore, complicated. This was illustrated during the signing of the *Energy Island project covenant* on Goeree-Overflakkee. There, a variety of experts agreed on the need and feasibility to implement electricity storage in the local grid to enable the development of multiple energy related projects. However, none of the parties were willing to take responsibility for this specific part ("*Convenant Groene Waterstofeconomie Zuid-Holland: Proeftuin Energy Island Goeree-Overflakkee (H2G-O)*", 2017; "*Programma Duurzaamheid Factsheet stand van zaken gemeente Goeree-Overflakkee 2016*, 2016; "*Succesvol Energy Island Goeree-Overflakkee congres*", 2017). Apparently, the combination of institutional factors on a practical level negatively affected the agreements previously reached on a general level.

Academic Relevance

Studies often focus on specific well-defined and measurable aspects of a techno-economic system, but thereafter fail to integrate the influence of relevant *institutional factors* when devising a strategy and assessing its feasibility of adoption. The academic challenge is thus to detect relevant factors and to quantify their perceived level of influence.

Kern and Smith (2008) reviewed the transition management model used by the Dutch government in 2001. The model was developed to determine long-term visions and strategies in the Dutch energy sector. The high number of large companies compared to *Small and Medium-sized Enterprises* and the low participation of governmental and scientific organisations led to a selection of strategies that did not lead to innovation. Türkay and Telli 's (2011) research claim that only *hybrid systems* adhere to the demands of a sustainable and robust energy-infrastructure. These systems integrate renewable electricity generation with storage applications. However, '*while modelling this technically feasible and economically viable system, the constraints such as consumer preferences, social and institutional barriers, financial barriers etc. were assumed to be non-existent.*' (2011, p. 1931).

The academic problem is thus generic. The *research questions* and pursued *deliverables* devised to conduct the research are however specifically delineating towards the topic of this thesis.

1.6 The Research Questions

The presented reasoning executed until now leads to the main question for this thesis:

'Why is electrical storage not widely implemented in the Dutch electrical infrastructure and how can this be explained by institutional factors?'

As discussed, there are a large number of relevant factors. As such, this thesis aims to provide the answer to the main question by exploring six sub-questions.

The Research Sub-Questions

This thesis answers the following sub-questions:

With regard to the implementation of electrical storage for balancing purposes in the Dutch power grid:

RSQ 1) *What are the possible roles and utilities?*
RSQ 2) *Can they effectively fulfil these roles?*
RSQ 3) *Which institutional factors influence implementation?*

In order to gain insight on the influence of institutional factors, it is necessary to quantify the relative composition of viewpoints of relevant actors. As such, the following sub-question for this thesis are:

With regard to the implementation of electrical storage for balancing purposes in the Dutch power grid, how do the various actors perceive:

RSQ 4) *their roles;*
RSQ 5) *their capacity to fulfil these roles;*
RSQ 6) *the influence of the institutional factors?*

The exploration and answering of these questions leads to the development of the research deliverables.

1.7 Research Design and Deliverables

This thesis and research are exploratory in nature. It consists of two phases. Each phase results in a set of deliverables, acting as substantiation for the discussion and conclusion. This is illustrated in *Figure 1- The Research Design*.

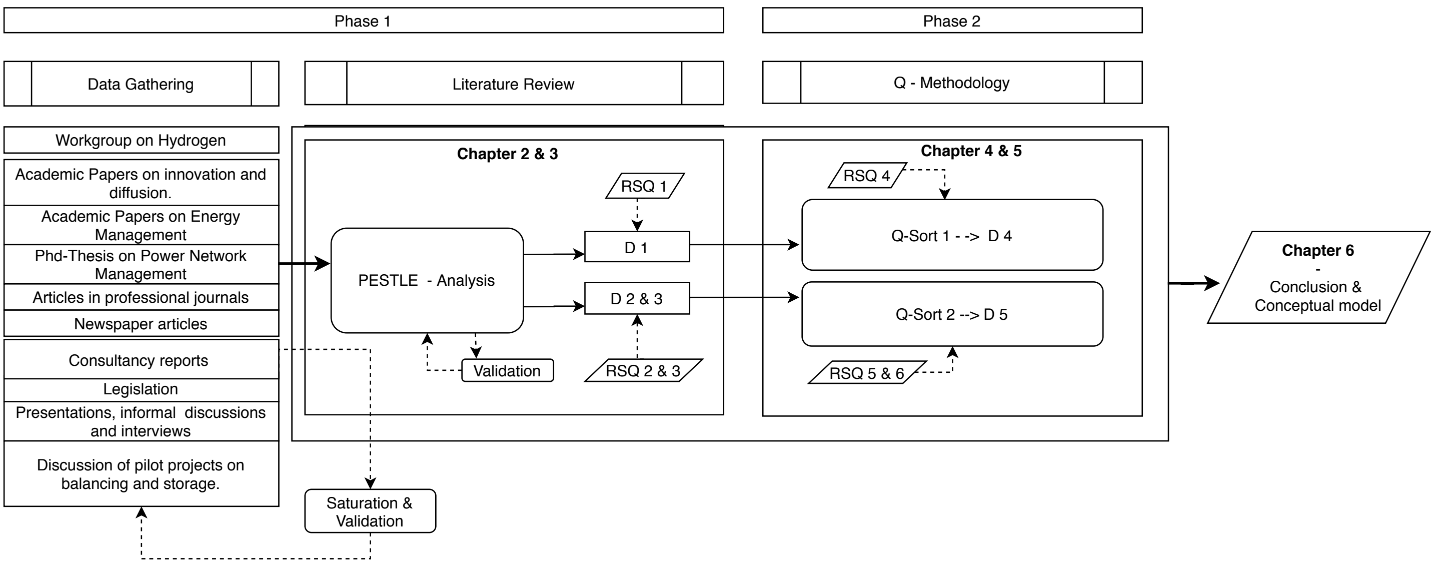

Figure 1 - The Research Design

An Introduction to Q-Methodological Research

Q-Methodology is a method introduced by William Stephenson in 1935. It differs from other statistical research methods as it regards the respondents as the variables in the study. As such, the *units of analysis* consist of the opinions and perspectives of respondents. The goal is to provide insight into the various perspectives within the sample of respondents, as well as to map groups with equivalent viewpoints (Bouwman et al., 2012; Watts & Stenner, 2012).

Q-Methodological research investigates human subjectivity, in order to illustrate why and how actors believe and act the way they do. '*It combines the gathering of data with subsequent intercorrelation and factor analysis to reveal the key viewpoints among a group of participants*' and '*thereby potentially identifying a group of persons who share a similar perspective*' (Watts & Stenner, 2012, pp. 12, 24). The research can illustrate where respondents differ in opinions. The difference in perspectives are often not uncovered during discussion on a general level. To quote Cuppen et al. (2010, p. 580): '*Negotiations are only possible if people understand their own and others preferences.*'

The insight in the different perspectives concerning the various institutional factors, could break the deadlock in the decision-making process with regard to the implementation of storage applications in the power grid.

Q-Methodological research sets requirements to the way data is structured. The data collection and structuring is executed to meet these requirements. Cuppen et. Al (2010) describe the following stages in a Q-Methodological Research:

Compiling the Concourse: This is the full compilation of viewpoints on the focal topic.
Define the Q-Set: The creation of a list of statements drawn from the concourse in such a way that it covers all opinions and is presented in a non-value laden manner.

These two stages constitute the first phase of the research. The following four stages are part of the second phase of the research.

Define the P – Sample: This is the selection of respondents. This should represent a balanced and full spectrum of opinions.
Execution of the Q-Sort: The forced ranking of the statements in the Q-Set by the participants.
Statistical analysis of the Q - Sort: This is the search of perspectives through the statistical evaluation of the values attributed to individual statements.
Interpretation: This is the description of the perspectives. This step largely depends on the experience and objectivity of the researcher. However, when performed correctly, the statistical analysis is reproducible.

The Literature Review and the PESTLE Analysis

The goal of the literature review in Q – Methodological research is to create the concourse, which is an extensive overview of the available data on the topic at hand. *'The concourse can be elicited from any number of sources. Academic literature, literary and popular texts, interviews, informal discussions and pilot studies. The exact nature of the sampling is of little consequences'* (Watts & Stenner, 2005, p. 75*).* From this concourse, a set of statements is filtered representing a balanced illustration of the topic; the Q – Set. This Q – Set is the input for the Q – Sort executed in phase 2.

The data collection leads to an extensive and unstructured amount of data. Structuring this data is important for the development of the Q – Set, as, according to Watts and Stenner: *'A balanced Q-set ensures is not value-laden or biased towards some particular viewpoints' (2012, p. 65)*. The structuring of the data is done by subjecting the concourse to a PESTLE Analysis.

The PESTLE analysis is recommended in literature on strategic management and decision making (Bertozzi et al., 2006). It is a guideline to analyse the relevant external macro-environmental factors influencing the trajectory of technology and associated decision-making processes. All statements gathered in the Concourse are first categorized in *political, economic, societal, technological, Legal* and e*nvironmental factors*. Subsequently, the factors considered irrelevant for this study are removed. This is based on literature and in consultation with an energy expert.

Finally, a selection of the remaining statements is made in order to compose two Q – Sets. The first Q – Set constitutes **Deliverable 1**. It investigates the anticipated roles and utilities of storage applications. The second Q – Set is **Deliverable 2**. It summarizes the institutional factors influencing implementation. Furthermore, it explores whether these factors are currently considered as an opportunity or as a barrier by the various sources used for this research. This leads to **Deliverable 3**.

It is possible to distinguish between the *Initiation* and *Adoption of Change.* This is based on the theories on market development set forth by Rogers (1983). In *Diffusion of Innovation*, Rogers describes how external forces influence the decision-making process and the trajectory of an innovation. Furthermore, it presents strategies a *change agent*, or initiator of change, can employ to steer this process. This is needed when market forces hamper desired change. These ideas, which can still be found in more modern literature, are relevant for this thesis. F*igure 2* illustrated the initial conceptual model for this thesis. The research aims to provide a more detailed and profound insight in this model.

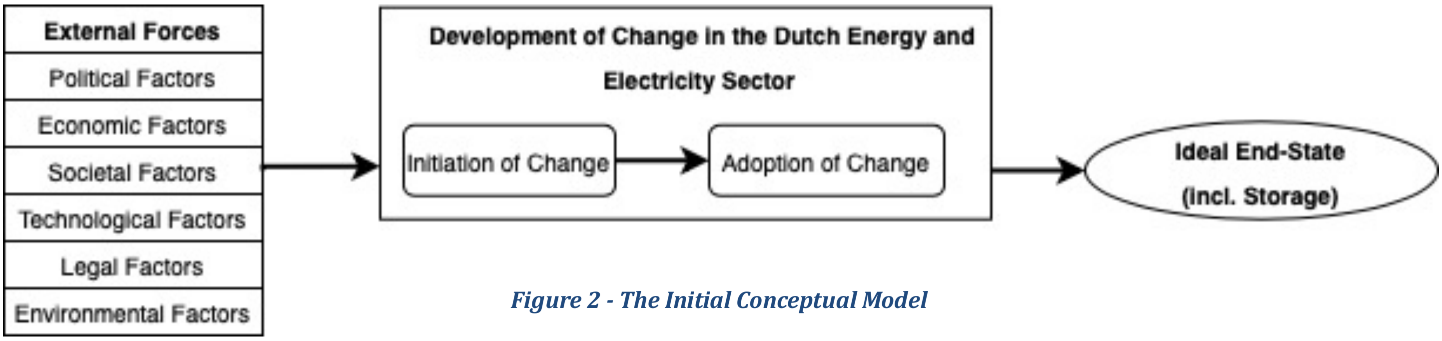

Figure 2 - The Initial Conceptual Model

The Q – Sets are designed to contain an equal distribution of statements over the macro-environmental factors associated with the PESTLE-analysis. They are the end-product of phase 1 and are input for phase 2, the Q – Sort and its analysis.

The Q-Sort and the Statistical Analysis

A Q – Sort differs from most questionnaires. The respondents are not encouraged to value the statements independently, but to order them in relation the extent to which they agree with them. As such, the respondents are forced to view each statement in relation to the absolute topic at hand. Furthermore, respondents are asked to provide qualitative feedback. The result of the Q – Sort is thus both quantitative, consisting of the forced distributions of the statements and qualitative, provided by their feedback.

The next step is to subject the sorts to a statistical analysis. This analysis uses the respondents as variables and compares their individual sort to the average distribution of the group. The analysis groups respondents with comparable perspectives and highlights the differentiating statements between perspectives.

The result of the statistical analysis of Q – Sort 1 is **Deliverable 4.** This is a delineation of how the respondents view the role of storage applications. **Deliverable 5**:is an illustration of how the respondents perceive the various institutional factors with regard to the implementation of storage applications. This is deducted from the analysis of the second Q – Sort.

Concluding Chapter

In the final chapter, the information filtered from the literature review is compared with the results of the Q – Sort analysis. The final delivery of this thesis is not a substantiated scientific theory. The research is exploratory in nature. It aims to provide substantiated propositions describing the external forces currently influencing the development of changes in the Dutch electricity sector in general and the implementation of storage applications in particular. Its final objective is to provide a conceptual model in which the main concepts and their relations are stated, as is often the case in qualitative research (Den Boer et al., 1994).

1.8 Organization of Thesis

Chapter 1 - Introduction

This first chapter of this report delineates the subject and research purpose of this thesis. It discusses the various causes for the need to implement additional balancing mechanisms in the Dutch power grid. Furthermore, it introduces electricity storage as a viable option to do so. The research questions and objectives are described, and a brief overview of the research is given: a combination of a PESTLE analysis and Q-Methodological Research.

Thesis Continuation

Chapter 2 - Domain

This chapter discusses the working operations of the power grid. An emphasis is put on the scope of the thesis: the Dutch power grid. A PESTLE analysis is executed to provide a substantiated list of factors and actors that influence the development of the electrical sector. The findings are compared to the results of existing reports written on the subject.

Chapter 3 - Literature Review

There is ample discussion on the applicability of electrical storage for utility purposes. Furthermore, various research discusses the costs and benefits of storage for society from the perspectives of technology and economy. This literature review provides an account of the different views on this subject. Moreover, the findings on market development and innovation management provided in literary sources is compared to the developments in the electricity sector in general and the maturity of storage applications in particular.

The statements for the Q – Sets are filtered from the information provided in chapter 2 and 3.

Chapter 4 - Methodology

The research approach is described in this introducing chapter (chapter 1). Chapter 4 discusses the execution of the Q-Methodological Research and PESTLE analysis in more detail

Chapter 5 - Findings

The statistical outcomes of the Q-Sorts are presented in chapter 5. The background information provided by various respondents – which is coupled with the information gathered in the earlier chapters – is used to discuss the implementation of storage applications. This analysis answers research sub-questions 4 to 6.

Chapter 6 – Conclusion, Discussion and Propositions

The final chapter aims to answer the main research question, based on the findings of the Q-Methodological Research and the Literature Review. The final result is a conceptual model showing the influence of the external forces depicted in the PESTLE analysis on the implementation of electrical storage applications in the Dutch power grid.

2. Domain

This chapter describes the historic development of the Dutch electricity sector. It emphasizes on the power grid. The information is structured through a PESTLE analysis. When applicable, the information is translated to *statements.* These are included in the Q – Sets for the Q–Methodological research. The sources used for this chapter vary from interviews to newspaper articles. As such, they have various levels of scientific support. Therefore, the statements are substantiated in chapter 3. This can lead to recurrence of information. The final Q–Sets and their extensive source references can be found in *Table 3* and *Table 4* of *Appendix 3.*

First, a basic description of the Dutch power grid is given.

2.1 Working Principles of the Power Grid

Figure 3 **- Simplified Anatomy of the Dutch Power Grid** illustrates the Dutch infrastructure but might also be applicable to other nations in which the vast majority of the built environment is coupled to a power grid. The stakeholders are discussed more extensively in the later part of the chapter.

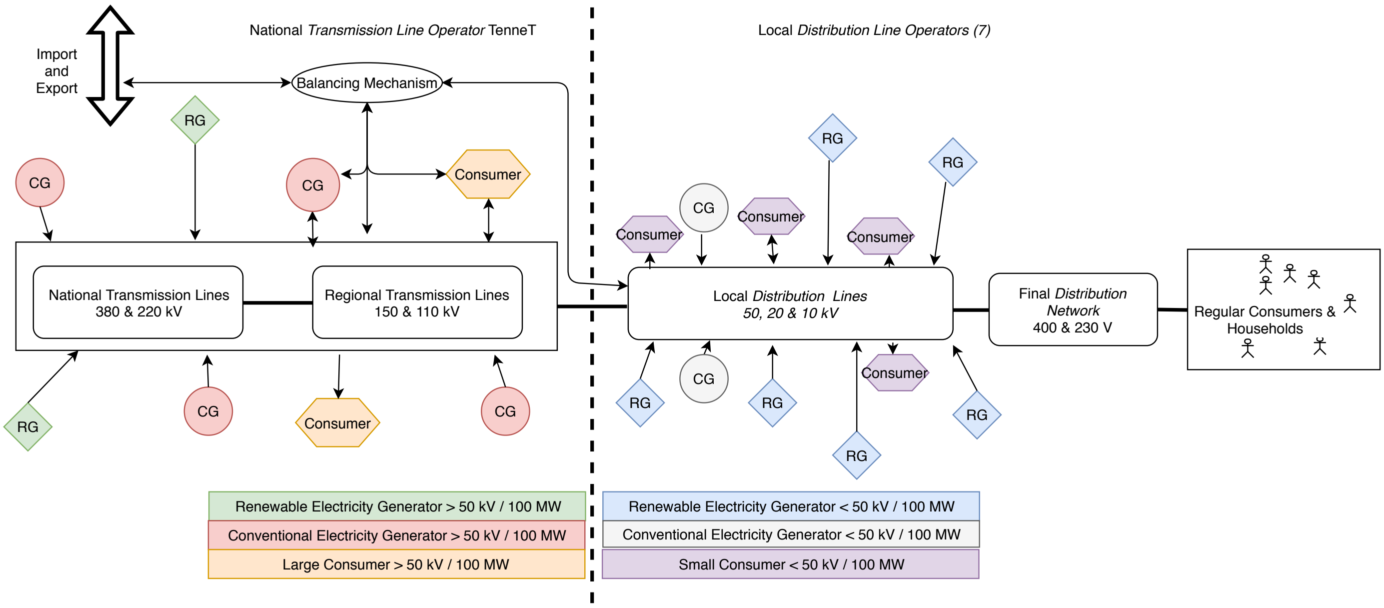

Figure 3 - Simplified Anatomy of the Dutch Power Grid

Sources: Adapted from Dell & Rand, 2001; 'Hoogspanningsstations - Knooppunten in onze elektriciteitsvoorziening', 2017; 'TenneT - Welke Aansluiting', n.d.; van Wijk & Verhoef, 2014.

The power grid is defined as the infrastructure that transports and distributes electrical energy from multiple electricity generators to the end-users. This infrastructure can be broken down into two main components: the transmission system and six distribution systems.

The transmission system consists of the high-voltage power *Transmission lines* (110 to 380 kV). This system is fully owned and operated by TenneT, the Dutch *Transmission System Operator (TSO)*. The Dutch national government is their sole shareholder. The responsibilities of the *TSO* are subdivided into three main duties These are the provision of *electrical transport services, market allocation*, and *system services.*

Electrical Transport Services

TenneT is responsible for the maintenance and development of the high-voltage power transmission lines and associated systems. These systems include the *interconnectors*, enabling the flow of electricity between networks. The transmission lines transport the bulk of the generated electricity to the six national distribution systems.

TenneT is responsible to provide access to the transmission system for the six distribution networks and for large consumers and generators of electricity. The latter consists of larger industrial entities, requiring connections of 50kV/100MW and above. This applies to the majority of *conventional electricity generators* and some of the renewable generation sites. This is shown in *Table 1* of *Appendix 2*. All offshore users are coupled directly to the transmission system, regardless of the required connection.

The transmission systemalso enables the import and export of electricity to foreign transmission systems. For this, TenneT cooperates closely with foreign TSO's in the *European Network of Transmission System Operators for Electricity,* (ENTSO-E). This consists of 42 *Transmission System Operators* representing 34 European countries. This is shown in *Figure 4 - The Composition of ENTSO-E*

(A. Anagnostou et al., 2018).

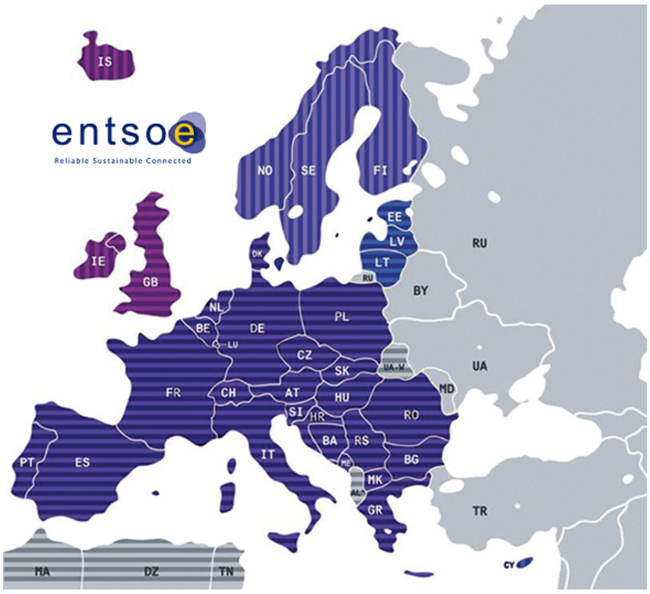

Figure 4 - The Composition of ENTSO-E

Source: Copied from (A. Anagnostou et al., 2018)

Market Allocation
The above describes the physical aspects of the transmission system. The system also consists of the multiple markets to manage the trade of electricity, both nationally and internationally. This is discussed in more detail later in this chapter.

System Services
The *system services* are subdivided into three categories: *Measurement Responsibilities*, *Congestion management,* and *Grid balancing*.

The *measurement responsibility* is needed to manage the closed electrical energy cycle. It involves short and long-term planning of electricity generation and usage in order to allocate appropriate transport and interconnector capacity to each user of the system. The actual utilization is measured in order to determine the deviations between the planning and actual usage. This information is used to determine the total costs of energy transportation. It is also used by the *Autoriteit Financiële Markten* (AFM) to monitor whether traders adhere to their contractual obligations.

Congestion Management involves the prevention of overloading parts of the power grid due to the increasing load on the power lines. This is needed because generators and users of electricity tend to group in different regions. Furthermore, the cross-border trade of electricity is increasing. Therefore, electricity is increasingly transported between networks,

Maintaining the Net Balance consists of the real-time management of supply of and demand for electricity in the power grid. A balance enables a reliable and smooth electricity supply. This is done at national and regional levels by the TSO. In order to mitigate with deviations, the TSO controls reserve capacity in the *balancing market*. This entitles TenneT to force conventional generators to temporary increase production and to oblige large consumers to temporary assimilate more electricity. This is illustrated by the bidirectional arrows in *figure 3.* There is a trade-off, however. A large reserve capacity is needed for sufficient balancing mechanism but also causes the system operator to become a major actor in the generation market. On the other hand, a small capacity has limited effect on market forces but is insufficient to mitigate with all deviations in the power grid.
The Distribution System Operators (DSO) are responsible for the balance in their assigned regions.

The Distribution System

TenneT is thus responsible for the national transports of electricity to and between the six distribution systems. These systems consist of power networks in designated areas. The dedicated *Distribution System Operator (*DSO) has comparable duties to the TSO on these networks. It distributes the electricity for local municipality usage (50 – 10kV) and provides the final distribution to the regular end-user such as households (440 and 230V). The DSO is also responsible to provide the physical access to the regional users. This includes small electricity generators (<100MW/50kV connection)

The majority of renewable electricity generation sites are *small electricity generators*. As a result, the distribution systems are increasingly being used for inter-area electricity transport. According to Gottwalt et al.: '*The existing power grid is designed for the one-way distribution of electricity from few large, constantly generating power plants. Hence, the increasing share of renewable energy sources, which are decentralized, small units with variable capacity, conflicts with the current power grid control infrastructure' (2011, p. 8163).* As a result, the challenges and responsibilities to perform grid management are thus increasing and shifting from central to local management.

The duties of the network managers is to enable the continuous provision of electrical energy to households, social services and industry. Furthermore, the challenges to balance the grid is increasing due to the decentral locations of generations sites. This leads to the following statements:

> Q-Set 1: To maintain the current reliability to enable economic security.

> Q-Set 1: To maintain the current reliability to maintain the current standard of living.

> Q-Set 2: The decentralized location of renewable electricity sources.

2.2 Political and Legal Factors[1]

This paragraph delineates the Dutch policy influencing the development of storage application in the power grid. It is combined with the legal factors of the PESTLE analysis. This is done because policy is often enforced by regulations.

Latest Political and Regulatory Developments

The Dutch energy sector is regulated by the *Stimuleringsregeling Duurzame Energieproductie (*SDE+), adopted in 2011. This legislation is currently up for renewal in parliament. The renewal aims to include regulations on the usage of the Dutch power grid. This is innovative, as so far, Dutch energy policy and legislation has focussed on the generation and usage of electricity. It paid little attention to the power

[1] This paragraph is based on the following sources: (Boeters, 2018; Bongaerts, 2018; "32813 Kabinetsaanpak Klimaatbeleid—Motie van het lid Sienot C.S"., 2019; "*Ruime steun voor waterstof in Tweede kamer*", 2019; Dell & Rand, 2001; Hoogma, 2017; Johansson & Turkenburg, 2004; Kern & Smith, 2008; Koç, 2015; Marijnissen, 2020; Straver, 2020; van de Poll, Wilfred, n.d.; van der Berg, 2019; van Dril, 2018; van Swaay, 2018; Verbong & Geels, 2007; Weeda & Gigler, 2018)

Q-Set 2: The political attention with regard to the reliability of the network.

Q-Set 2: The political long-term vision of the network.

grid's operations and its facilitation. As such, the successor to the current legislation, the SDE++, views the electricity sector from a holistic view, stimulating the cooperation between generators, system operators, and users.

In September 2019, before its endorsement in parliament, the members of parliament Sienot, Harbers and Mulder submitted a motion to alter the current delineation of the SDE++. They requested to include the usage of storage application for electricity, as well as the usage of alternative energy carriers such as hydrogen, in the framework. The final discussions and subsequent endorsement of the legislation have yet to take place.

Q-Set 2: The political knowledge regarding the possibilities of storage.

Q-Set 2: The schemes for subsidies for storage.

The political attention for storage applications is new. There is, as of yet, no legislation that specifically describes this topic in any way. The developments are so far indirectly influenced via regulations on other topics. For example, TNO states that the storing of electricity through the conversion of electrons to molecules such as hydrogen, is currently hampered by EU and national regulations. Although the EU recognizes hydrogen as a renewable energy carrier in the transportation sector, the same does not apply in the electricity sector. The Dutch national law on gas forbids to blend more than a 0.02% of hydrogen in the natural gas grid. This hampers the development of a viable business case for storage.

Q-Set 2: The regulations regarding implementation of storage.

Finally, the integration of storage application is hampered by the law on network management, or *Wet Onafhankelijk Netbeheer* (WON), implemented in 2008. The law strictly limits the duties of the network managers and electricity generators. Furthermore, it forbids any commercial stakeholders to have an interest in both network management and power generation. This indirectly forbids the implementation of storage applications by individual parties and the cooperation between multiple parties to create a joint business case.

Q-Set 2 The law permits the implementation of storage.

The Timeline of Influential Policies and Regulations

The current situation in the Dutch power grid is shaped to meet the development of policies and regulations on the topics of energy and climate. Next, a timeline on both topics is discussed. An illustration can be found in *Figure 1 – Timeline of EU and National Policies and Regulations with regard to Energy and Climate* in *Appendix 2*.

The Dutch energy market has its roots in the 1960s and 1970s. It has been driven by Europeanisation and Liberalisation. An open market was expected to lead to low prices, optimal quality and innovations. After the oil crises of 1973 and 1979, the topics of energy security and scarcity became political issues. The combined focus on liberalisation and energy security resulted:

On the one hand, the formation of major commercial energy companies trading in fossil energy *carriers*, albeit protected and subsidized by policy and*;*
On the other hand, the governmental ownership of the national power grid.

Therefore, up until the 1980's, the electricity sector was organized hierarchical and under governmental control. The Dutch electricity generation and infrastructure thus developed as a societal system, based on fossil-based fuels. These fuels are delivered by the energy companies discussed above. The liberalisation of the electricity sector led to low electricity prices. However, the associated increase in international trade increased the problems in net balancing.
The *Dutch Law on Electricity* (Elektriciteitswet Nederland), was accepted in 1989. Its aim was to enforce the liberalisation of the electricity and gas sector by returning control to market parties. Most energy companies remained vertically integrated, owning both the generation facility and the distribution network. Moreover, provincial and local authorities remained major shareholders.

On December 19th, 1996, the European Union passed Electricity Directive 96/92/EC, followed by 98/30/EC on June 22nd, 1998. This led to the regulatory distinction between the generation, transportation and trade of electricity and gas as free economic activities. This ensured access to the grid for all generators and thus created a demand-driven electricity market in which consumers can choose their energy provider. The Dutch Law on Electricity was altered in 1998 to adhere to these regulations. In order to ensure good network management, the act also appointed one single operator per region. In order to include competition, the revenue model associated to network management is now arranged by basing prices on the efficacy between the independent network management.

In 2003, the European Directives are superseded by *Directive* 2003/54/EG and 2003/55/EG. As a result, the *Dutch Law on Electricity* was supplemented by the *Wet Onafhankelijk Netbeheer (WON)* in 2004. This law enforced the dissolution of Vertically Integrated Companies to economically independent network management and electricity generation companies. Furthermore, it led to the formation of a single governmental controlled Transmission System and six regional Distribution Systems owned by market parties.

In 2008, this law is supplemented by the *'Groepsverbod'*. This law prohibits any financial and legal interests between network management and the generation and trade of electricity. The same applies on European level in 2009, after the endorsement of the so-called 'Third Package'. The regulatory framework stipulates the European trade of electricity and the obligation to provide all parties access to the grid against pre-defined tariffs. This completes the liberalisation of the European energy sector.

The policy on climate developed independently from the policy on energy. In 1996, the *Wet Regulerende Energie Belasting (REB) was* introduced. This law was developed to create environmental sustainability in the tax system, by providing tax refunds to the development of renewable electricity generation projects. As a result, the law on electricity was altered to introduce the *Transition Act for the Electricity Production* in 2000. This act returned the ownership of the Dutch *Transmission System Operator,* TenneT, to government. This was needed to provide the investments needed to enable to the integration of renewable electricity infrastructure on the European grid. These were not expected to be recoverable in a competitive market. In 2003, the tax refund was replaced by a subsidy in the *MEP*, the *Wet Regeling Milieukwaliteit Elektriciteitsproductie.* This was needed because the liberalisation of the market enabled the cheap import of renewable electricity. As a result, the national generation of renewable electricity remained limited, while tax refunds were paid to foreign companies. The power grid later proved to be insufficient to cope with the development of renewable generating sites, which led to high costs. The *MEP* was therefore terminated in 2006. As a result, the implementation of renewable generation projects decreased from 416 MW (2008) to 30 MW (2010). Therefore, the *Stimuleringsregeling Duurzame Energieproductie* (SDE) was developed in 2008. In order to deal with balancing challenges, the amount of the subsidy became time dependent.

In 2012, the EU adopted *Directive 2020/27/EU* to meet the EU climate goals. This led to a shift in political objectives from economic to sustainable efficiency, and indirectly to the recognition of the role of the energy infrastructures. This circles back to the submission from the members Sienot, Mulder and Harbers discussed previoulsy, and possibly the implementation of a regulatory framework in support of storage applications in 2020.

The following paragraph summarizes various reports describing the influence of policy and regulations on the development and current state of the Dutch electricity sector.

Reports on Dutch Policy Influencing the Energy Infrastructure

Historically, policy and legislation focussed on energy security and affordability. This led to the dominance of fossil-based electricity generation. Moreover, the existing policy and regulations strictly separate the various energy infrastructures. Consequently, the regulations are ambiguous on the applications of storage in the various networks.

Dutch energy policy has been increasingly criticized for the dominance of fossil energy companies in the working groups discussing energy and environmental policy. This frustrates incentives to invest in alternative sources of energy. Furthermore. it hampers the inclusion of the costs associated to environmental damage in the prices of electricity.

Q-Set 2: The integration of environmental damage in electricity prices.

Regarding policies and pursued objectives, many changes occur, these sometimes involve adjusting definitions or reversing previous regulations. The regulatory definition of *energy* or *CO_2 neutrality* for example could originally be achieved by means of purchasing *renewable energy certificates* to offset one's own use of energy. The current, more stringent, definition of *neutrality* is achieved when an entity generates more electricity than it uses itself. Both definitions focus on the generation and usage of electricity and thus fail to account for the capability of the grid. As such, although there has been significant support for and investments in change towards renewable energy in the new millennium, investors lack security due to the absence of long-term vision, knowledge and commitment with regard to the policy that influences the energy infrastructure. This has recently been confirmed in Germany, in February 2019. There, politicians and economists openly doubted the requirement for a 34 to 52 billion investment in the power grid to enable the energy-wende. This happened because the national electricity generation was already close to reaching *neutrality*. In reality however, the grid was not capable to transport the surplus of renewable electricity generated in the north-eastern part of the country to mitigate with the shortages in the south-eastern regions.

Q-Set 2: The regulatory ambiguity of the term "energy neutral".

Furthermore, the developments in policy revolved solely around the topic of energy. It failed to include developments in legislation with regard to environmental protection. Moreover, the policies were developed independently for specific sectors. There is thus neither holistic view nor central political coordination on sustainability.

Q-Set 2: The clarity of the political vision with regard to sustainability.

Because of this, network operators are forced to connect generators on a "first come, first serve" basis, meaning that the current regulations hamper the application of smart grid design. There is, however, increasing political attention for the sustainable use of electricity and its infrastructure, both on national level and in the European Union. This includes the development of flexibility via storage in the power grid.

2.3 Economical Factors[2]

This paragraph discusses the development of the market environment of the Dutch electricity sector. It refers to policies and regulations described in the previous section. The timeline is illustrated in *Figure 2 – Timeline of Economical and Market Development of Network System Operators* in *Appendix 2*.

As previously discussed, energy companies are forced to create independent network management companies within their holdings in 1998. *Table 1* shows the active licence holders in the market at the time. The network operator and the energy supplier were both determined by the place of residence. Subsequently, in 2004, the liberalization of the market is completed by the creation of independent

[2] This paragraph is based on the following sources: (Rogers, 1983)

companies for network management and electricity generation. In 2006, the *WON* was implemented and later supplemented with the *Groepsverbod* in 2008. The implementation was complete in September 1st, 2017, when the newly formed distribution system operator Coteq was split from the holding Cogas.

Table 1 - Dutch Vertically Integrated Energy Companies

Before *Dutch Law on Electricity - 1998*	Before *Dutch Law on Electricity - 2004*	
Integrated Energy Companies	Distribution Operator	Electricity Supplier
Eneco	EnecoNetbeheer	Eneco
Essent	Enexis Netbeheer	Essent
Nuon	Continuon	Nuon
Rendo	Delta Netwerk Groep	Delta
	Westland Infra	Westland Energie
	Rendo Netwerken	Rendo

The law led to major changes in the energy landscape. The European power grids are now interconnected and led by independent market companies. This enabled smaller generators to compete with incumbent energy companies. As a result, the number of stakeholders more than quadrupled. This is shown when comparing the situation in 1998 and 2004, as shown in *Table* 1 above and the situation in 2018, depicted in *Table 1* of *Appendix 2*.

The increase of competition on the national and European market reduced the electricity prices paid by the consumer, but simultaneously reduced the financial stability of energy companies. Many have huge debts, go bankrupt, or are taken over. In 2014, the *Autoriteit Consument and Markt*, the Dutch body supervising the competition between companies, reported that investments up to 37 billion euro were needed in order to adapt the power grid to meet the Dutch energy agreement. In 2015, the Dutch energy companies and network managers terminated their participation in this agreement. The companies stated that the forced split of the vertically integrated companies and the increase in competition led to insufficient turnover to enable the required investments. *Figure 5* shows the result of a research executed in 2016. The market prices of electricity are shown to be lower than the average life cycle costs of electricity generation. The market prices were almost equal to the *marginal* costs of electricity generation of *existing* generation sites. The investments in new generation facilities, or in flexibility such as storage, would only increase the marginal costs of electricity. Therefore, there are little economic incentives for commercial companies to invest.

Q-Set 2: The overall costs per kWh of stored electricity.

Q-Set 2: The political recognition of balancing problems.

The Timeline of Market Developments in the Electricity Sector

The Dutch and Belgium power grids were interconnected on May 25th, 1999. Simultaneously, the *Amsterdam Power Exchange (APX)* was founded, enabling the transparency in the trade of electricity between both countries. The prices of electricity and gas in both countries were now set on an hourly basis. The transmission grids and *APX* are jointly owned and operated by the TSO's, TenneT (70%) and Elia (30%). In 2000, *TenneT* becomes a state-owned company to provide the required investments to enable the increase in trade.

In November 2006, the *Trilateral Market Coupling* arranged the further market and grid extension to France. As a result, the prices of electricity and gas in the three countries were similar for about 70% of the time. Price differences arose only when the interconnectors that coupled the different countries overloaded.

The cooperation between countries was not limited to France, Belgium and the Netherlands. ENTSO-E, is founded in 2008 to work towards the interconnection of the five *synchronous areas.* The *Synchronous areas* are regions in which the national grids were already interconnected.

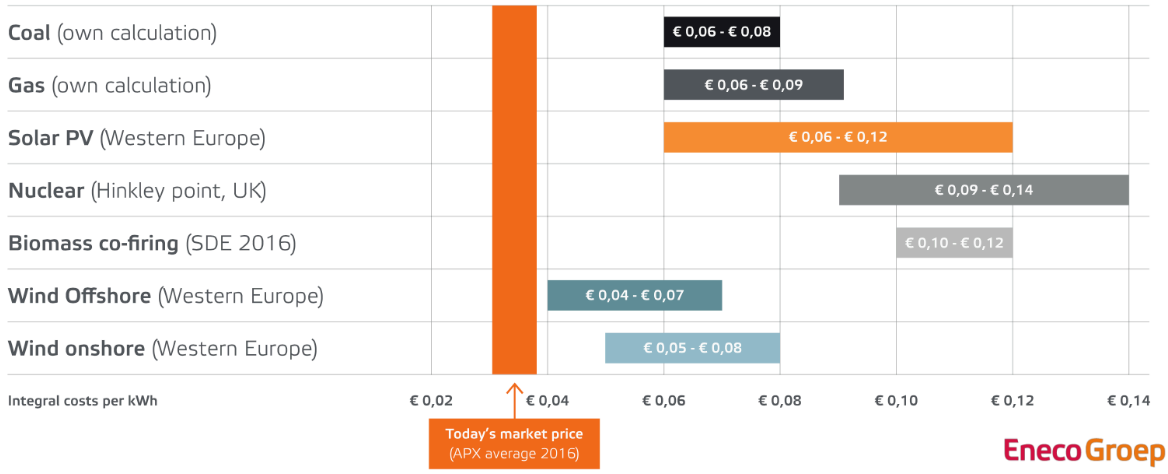

Figure 5 - Price Development of Electricity Generation versus Market Prices

Source: Copied from Presentation by the EnecoGroep, April 17th, 2018 during the IIR Conference on Energy Transition.

In 2009, the Dutch network operators sold their power lines in excess of 110 kV to TenneT. This completed the separation between the governmental owned national Transmission System and the six commercial Distribution Networks.

In 2010, the Dutch grid was coupled to Scandinavia, simultaneously expanding the exchange market *APX* with *NordPoolSpot*. Latyer that year, the expansion proceded to Germany and Luxembourg. Finally, in 2015, the European markets were merged into the *European Energy Exchange*. TenneT supplied two supervisory directors on behalf of the Dutch sector. The economic responsibility of the *APX* was reduced to the monitoring of import and export of electricity in the Dutch sector.

As discussed previously, the economic developments have led to changes in the market environment. The trade of electricity is increasingly done by third parties, buying and selling based on the lowest prices. In 2018, only six out of 59 Dutch energy suppliers generated their own electricity. The increase in trade and associated flow of electricity led to imbalances within the infrastructure. At the same time, a dichotomy arose between market and utility companies with regard to the costs and benefits of network management. This is discussed next.

The Business Ecosystem of the Dutch Electricity Sector

Figure 6 shows the separation between different entities and market conditions within the Dutch electricity sector. This is done via the development of a *Business Ecosystem*, based on the theory depicted by Moore in *Predators and Prey: A New Ecology of Competition* (1993). The business ecosystem is defined as an economical community, supported by, and constituting of, organizations and individuals and their mutual relations.

The trade of electricity and the utilization of the power grid happens throughout the whole supply chain of electricity. Traders are considered *electricity suppliers*. They deal in the supply and demand, but do not necessarily generate any electricity themselves. As such, most suppliers are brokers, acting as intermediary between generators and consumers. As previously discussed, the liberalisation of the electricity sector led to a significant increase of suppliers. The majority of these suppliers deal in the retail market, while the remaining suppliers deal in the bilateral market. The trade can be divided in the following markets:

The bilateral market involves the dealings between generators and large commercial customers. Despite the small numbers of traders active in this market, it consists of 85% of the electricity trade. Bilateral contracts are long-term and confidential.
The retail market involves the trade of electricity for small users such as households. Electricity is bought in the spot market.
The spot market is the short-term market. Power is traded in the APX on a day-ahead and hourly basis. Due to the lack of storage in the grid, the prices are highly volatile.
The balancing market is also operated by TenneT. It involves the trade of reserve capacity to enable the balance between supply and demand. When generators fail to provide their share of power or users consume in excess of their planning, additional capacity is bought from competitors against higher prices.
The trade in network capacity is managed nationally by TenneT. The capacity of the networks is traded through month and year contracts in auctions by the network operators. As the European liberalisation requires the cross-border allocation to be market based, ENTSO-E controls the auctions of the applicable interconnector and transmission lines.

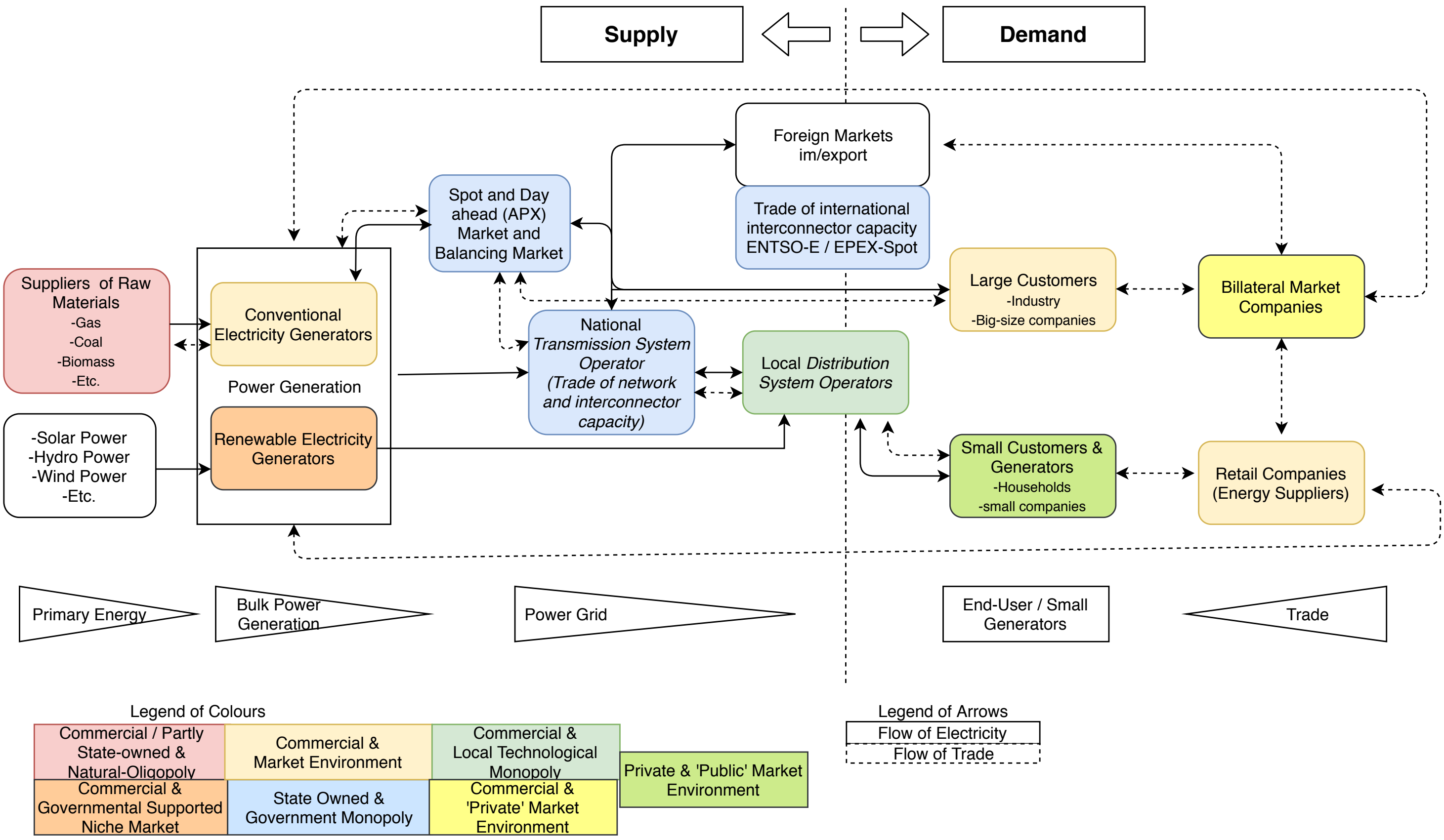

Figure 6 - The Business Ecosystem of the Dutch Electricity

The supply chain of electricity starts with the *Energy Companies*. They supply the primary energy used for conventional electricity generation. As previously discussed, historical policy primarily focussed on market liberalization and energy security. This led to the creation of major energy companies. Although these companies operate in a commercial market environment, these companies remain, to a certain extent, state-owned and subsidized. Furthermore, 50% of the worldwide market is in the hands of six out of 200 active companies. This constitutes a *natural oligopoly*, or a situation in which an economic product or service is provided by a limited number of suppliers and leads to disproportionate market forces. In case of renewable electricity, the starting point of the chain consists of primary energy originating from natural sources.

The Power Generators are the next link. Conventional electricity generation takes place in a commercial market environment. The liberalisation of the market led to an increase from six incumbent companies to over 24 generators. However, more than 70% of the supply is generated by four companies, which again constitutes an *oligopoly*. Although renewable generation operates in the same market environment, it is still a niche market protected and supported by government.

Next are the network managers, consisting of the Transmission and the Distribution networks. The transmission system and the *APX* are operated by the TenneT in a *state-owned monopoly*. The costs associated to network management, as well as part of the costs incurred to provide users access to the grid, are socialized through taxes. TenneT is however also responsible for maintaining the grid balance. Therefore, it procures reserve capacity in the *balancing* market. This reserve capacity is provided by commercial companies, consisting of conventional generators and big consumers.

Finally, the final distribution of electricity to the end-user is done by the six dedicated *Distribution System Operators.* As described previously, the DSO's have a *monopoly* within their assigned region. Their expenses are socialized according to the same principle as for the transmission system, but only over the inhabitants living in their region of operations. Their incomes are however based on a *state-regulated market environment*. The individual DSO's are paid a fixed price per distributed unit of electricity. This price is based on the average costs of the six operators. As such, operators make a profit if they manage to execute their tasks efficiently.

This pricing system has led to disproportionate availability of investments opportunities between regional network managers. This is due to an unequal distribution of generators and consumers between regions. To illustrate: the aggregated power output of Dutch solar parks was 638MWp in 2018, with an additional planned 2148MWp capacity. These projects are mainly developed in areas where land is relatively cheap, which is often regions with little urbanisation. On the other hand, big consumers of electricity, such as datacentres, are mainly built in areas with high population density. As both these small generators and consumers are coupled to their local distribution network, it influences the average costs of the applicable DSO's. Their benefits meanwhile transcend their specific region. The networks costs are thus not evenly distributed over the six managers. This led to less investments, affecting the quality of the network.

In 2018, the *PBL*, the Dutch planning agency for the living environment, estimated the costs associated to the energy transition to be 1.5 – 2.7% of the Dutch Gross Domestic Product, which is: '*Not too drastic for the Dutch economy as a whole, but too much for individual companies.* Therefore, c*ollaboration between companies, but also between market and government, is needed.'* The delineation of the timelines associated to policy, regulations and the developments in the market environment however illustrate strict separation between duties and the allocation of costs and benefits. Furthermore, it shows an increased number of stakeholders, which are divided in both a commercial and governmental environment. This has led to discussions about the responsibilities with regard to the required investments in the infrastructure. Moreover, it led to uncertainties with regard to the legality of storing electricity by the individual stakeholders. In time, the result is a lack of innovative development and the over ageing of current assets in the Dutch power grid.

2.4 Societal Factors[3]

The influence of society on the development of the power grid is very significant, but indirect. A large part was discussed in the delineation of the political, regulatory and economic factors. The influences are summarized as follows:

The recognition for environmental sustainability versus limited knowledge of the role of the power grid

The societal recognition for the damage attributed to climate change is increasing. Extreme weather conditions are one of the primary causes of power outage and is anticipated to aggravate. As such, the vulnerability of the grid is expected to increase. This threatens safety and can lead to economic damage. This results in increasing attention for the role of the power grid and the implementation of storage applications. From the point of view of society, this attention is however indirect.

Q-Set 1: To maintain the current reliability to guarantee safety.

[3] This paragraph is based on the following sources: (Diekman, 2017; Gottwalt et al., 2011; Johansson & Turkenburg, 2004; Koç, 2015; van de Poll, 2019; van der Stelt et al.; 2018; van Dril, 2018; van Wijk, 2017; Weeda & Gigler, 2018)

The damage caused due to power outages are partly allocated as penalties to the network managers. Network operators have expressed their disapproval. The lack of understanding for the role of the power grid has led to a disproportionate low allocation of resources for network management, compared to its considerate importance.

Q-Set 2: The societal attention with regard to the reliability of the network.

In January 2019, the DSO Enexis warned that the societal will to invest in renewable electricity does not match its acceptance to invest in the power grid. As a result, multiple renewable generation sites are not connected to the local grid in order to prevent overloading.

Q-Set 2: The societal recognition of balancing problems.

Q-Set 2: The societal support with regard to making the electricity sector more sustainable.

Q-Set 2: The social recognition of the benefits of renewable electricity.

An increasing aversion for natural gas

The reputation of natural gas in the Netherlands has become weak over the years. This is due to environmental concerns and the societal recognition of the damage in the province of Groningen. Meanwhile, there is a fear of using alternative gasses such as hydrogen. The latter is mainly attributed to a lack of knowledge. Current law limits the ratio of hydrogen in the Dutch gas infrastructure to 0,02%, while this ratio could be greater than 50% prior to the large-scale application of natural gas. The reputation of gas influences the application of storage in two ways:

It reduces the competitive position of gas, leading to an increase in electrification.

Q-Set 1: To enable handling the greater pressure on the network.

It indirectly reduces the economic viability of storage, since the conversion of electricity to hydrogen is considered the best technological option for storage in the Netherlands.

Q-Set 2: The societal knowledge and trust in storage.

The nett costs of electricity usage

Investments in the power grid are now instrumental to guarantee the security of electricity supply and to enable environmental safety. Furthermore, the implementation of local storage can, in time, reduce the costs of network management by 22 – 30%. Simultaneously, it can increase the efficiency of electricity generation by 23 – 39%. However, the societal support for investments is decreasing because the financial benefits are not tangible for households.

Q-Set 2: The societal acceptance of higher electricity prices.

2.5 Technological Factors[4]

This paragraph discusses the generation of electricity in the Netherlands from a technological point of view.

Electricity Generation

In 2018, 93% of the Dutch electricity generation was based on fossil *primary energy carriers*. *Primary Energy* is the original form of energy from which the electricity is derived. This can either be an *energy carrier* such as oil, gas, or biomass, or a natural form of energy such as solar, tidal, or wind power.

Conventional Electricity Generation (CG)

Conventional generation is defined as the production of electricity through the combustion of a *primary energy carrier*. This production is controllable and adjustable and has a high energy density. As such, a single plant can be designed to meet the local and additional demand of electricity. As described previously, the power grid was built to facilitate the conventional electricity generation. These generators were thus built in a central location that was close to consumers and power lines. Furthermore, *energy carriers* are storable and transportable without loss of internal energy. However, their combustion leads to the emission of harmful substances. There are three types of conventional electricity generators:

Base-Load plants

These plants provide the minimum continuous demand of electricity. They have relatively high efficiency at full power, but this deteriorates at partial loads. Furthermore, they have long start-up times and high start-up costs.

Intermediate-Load plants

These provide additional electricity when demand exceeds the base load. These plants have lower efficiencies but are operational within 1 – 2 hours.

Peak-Load plants

These plants can start and stop quickly, albeit at low efficiencies. They provide electricity during unexpected peak demands.

In order to provide balancing tools to the TSO, conventional generators are forced to maintain a *spinning reserve*. This is generating capacity that is online but unloaded. Therefore, it can respond immediately in case of primary generation or transmission failures. In turn, larger consumers are contracted to assimilate additional load in times of surplus.

Renewable Electricity Generation (RG)

Most renewable generation methods convert natural p*rimary energy,* such as wind, to electricity. In contrast to *conventional generation*, these methods have low energy densities and their output is not readily storable. In consequence, the generation sites are of relatively large size. Furthermore, their locations are often decentralized. Their output depends on the prevailing weather conditions and is therefore not stable nor controllable. The electricity is however generated without emissions. In 2018, the ratio of renewable electricity in the Netherlands was 6,6%. 68,4% of this electricity was based on the combustion of biomass. The generation of electricity via biomass is carried out via conventional methods. It thus has comparable benefits to fossil fuels. Although it is considered renewable electricity, the generation leads to harmful emissions.

As such, in 2018, only 2,1% of the Dutch power generation was of uncontrollable nature. Although these numbers are low, the implementation of renewable generating sites is a topic of consideration. This is because, as discussed, the capacity of the Dutch grid to handle more than 4GW renewable generation, or 7,3% of total production, is questionable.

The supply of renewable electricity often moves in opposite direction to its demand. When the share of renewable generation grows, it will eventually overwhelm the ability of the power lines. Therefore, *TenneT* and the *Gasunie*, its counterpart for the transportation of natural gas, investigated the options of

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[4] This paragraph is based on the following sources: ("*Aandeel hernieuwbare energie naar 6,6 procent*", 2018; Bongaerts, 2018; Crabtree et al., 2011; de Boer et al., 2014; Dell & Rand, 2001; Evans et al., 2012; Hall & Bain, 2008; Heinen, 2018; van der Meijden, 2017; van Dril, 2018; van Swaay, 2018; van Wijk, 2017; van Wijk & Verhoef, 2014; Weeda & Gigler, 2018; Wiersma, 2017)

integrating the two infrastructures. This could be achieved by converting electricity to a molecular energy carrier. In addition, this would be more efficient in terms of energy loss and financial costs by enabling the transport of energy via pipes instead of via transmission lines. The usage of an energy carrier could enable the import of renewable electricity from foreign countries.

Q-Set 1: To reduce the energy dependency on other countries.

The Netherlands has an excellent knowledge infrastructure on storage applications. This can create economic and employment opportunities. However, substantial investments are needed in theoretical and practical knowledge if storage applications are to be implemented on large scale basis.

Q-Set 2: The practical and theoretical knowledge of storage in the Netherlands

Q-Set 2: The presence of qualified personnel in the Netherlands.

2.6 Environmental Factors[5]

This paragraph focusses on the geographical factors influencing the implantation of storage applications and of renewable generation in the Netherlands. A report discussing these aspects in the United Kingdom is used as reference.

In 2007, the average daily energy consumption per capita was 310GW, or 125kWh, in the U.K Of this, approximately 14%, or 17 kWh, was used as electricity. According to *figure 7*, comparable numbers applied in the Netherlands.

The comparison of energy usage per capita versus the population density shows that 78% of the world's population lives in areas where the power consumption per unit area exceeds 0.1W/m^2. This includes the Netherlands.

The area needed to provide this power is deducted to be:

363 km^2, or 0.125% of the U.K.'s total surface, when using first generation nuclear power stations.;
16.000 km^2, or 6.5% of the U.K.'s surface, when using on onshore windfarms;
The use of bioenergy via crops would require 80.000 km^2, or 32,5% of the U.K.'s surface.

The area needed for nuclear- and bioenergy would be unusable for other applications, while the distance between individual windmills in windfarms does enable a secondary use. The number of nuclear power generators in the U.K. would need to quadruple to 60 power plants. In 2011, after the nuclear disaster in Fukushima, Japan, an area of 2827 km^2 (7% of the Netherlands) was evacuated and all cattle was preventively killed. After one year, tests cleared a large part of that area, but 315 km^2 was still considered too dangerous.

The renewable-only option would require 1000GWh of storage capacity per (near) windless and sunless day. This is 100 times the current storage capacity currently implemented in the U.K. Alternatively, the power lines required to import this electricity would be 750 meters wide at full capacity.

The numbers mentioned above are based solely on the usage of electricity. When the aggregated energy consumption is considered, the numbers should be multiplied by 7 – 8. Furthermore, the average energy consumption per capita has increased since 2007.

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[5] This paragraph is based on the following sources: (MacKay, 2013; *Position Paper rondetafelgesprek tweede EU-mobiliteitspakket*, 2018)

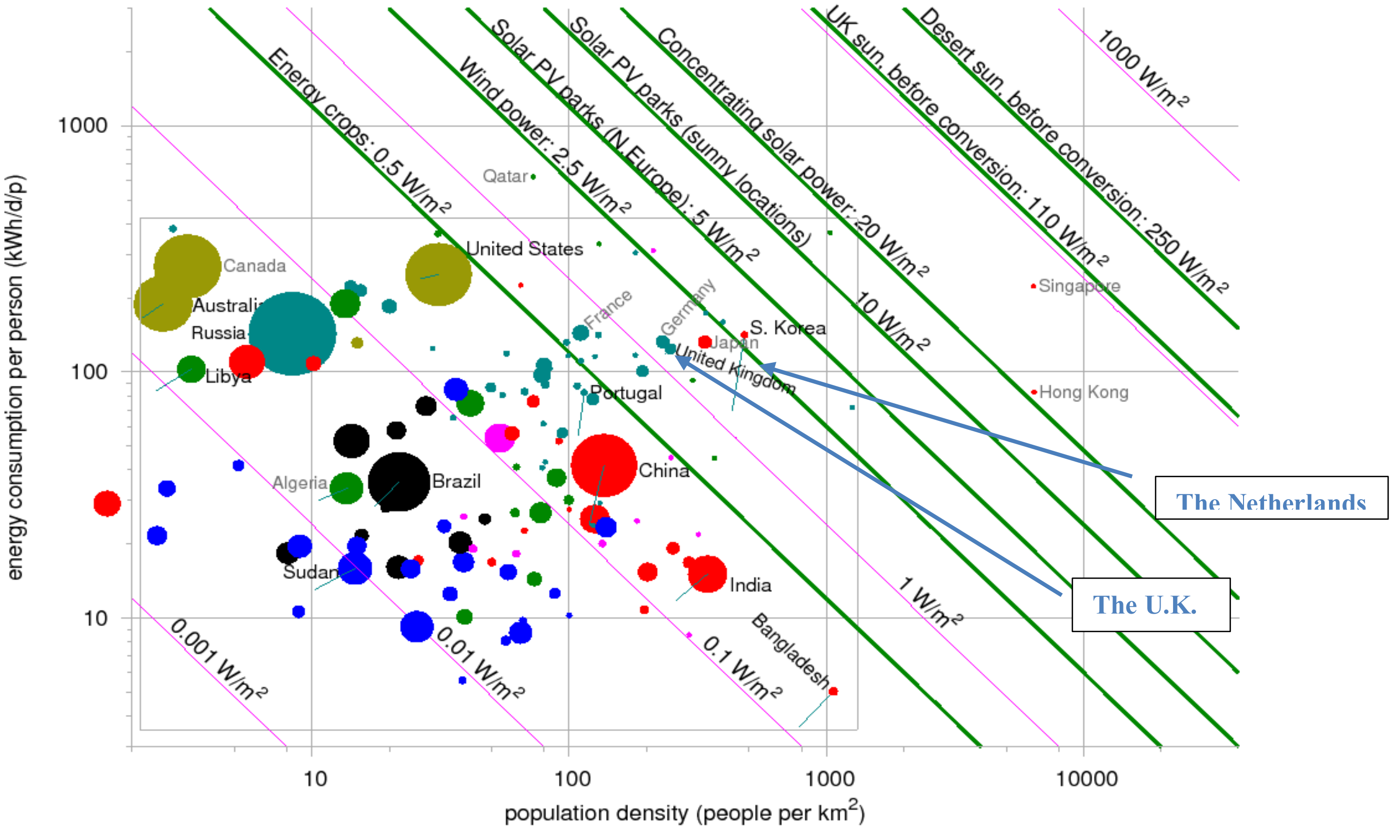


Figure 7 - Electricity consumption per capita versus required area for generation

Source: Adapted from MacKay, 2013

As such, energy management must be considered when planning the development of electricity generation, its usage, and the power grid. The role of storage is thus not only to provide balancing opportunities, but also to enable the large-scale transport of foreign renewable energy. The conversion of electricity into a molecular energy carrier would reduce the price of its transport by a factor 10 – 20 in onshore and by 100 – 200 in offshore situations. Large-scale storage is possible in salt domes. On average, these can hold up to 235GWh of energy stored in hydrogen.

Q-Set 1: To enable the import of "electrical" energy produced elsewhere.

Q-Set 2: The presence of geographical features required for storage.

The statements highlighted in this chapter are input for the Q-Sets. They are deducted from sources, ranging from copies of political hearings to newspaper articles. The following chapter substantiates the validity of these statements it also expands the list using new information.

3.Literature Review

In contrast to chapter 2, this chapter is based on academic literature. Furthermore, it does not solely focus on the developments within the *Dutch power grid*. Therefore, the literature review includes scientific substantiation for the various statements deducted in the previous chapter. This can lead to a recurrence of information. Furthermore, new statements are gathered when applicable. The lay-out is similar to that of chapter 2.

3.1 Balancing the Power Grid

The *systems services* provided by network operators have been previously described. The requirements to enable these services are discussed here. Evans et al. (2012) state three requirements for grid balancing, which are the capability to perform:

Power Quality Management

This involves the smoothing of power output on nano- and millisecond scale to maintain the grid frequency and voltage within strict levels (Koç, 2015). Failing to maintain either of the two can result in cascading failures in the entire grid. Power Quality Management thus requires systems with very quick reaction time and capable of delivering and assimilating different amount of power. The systems are needed to mitigate with small deviations. Therefore, the required energy capacity is limited.

Q-Set 1: Performing Power Quality Management.

The necessity to perform power quality management was illustrated only recently. Klaus Töpfler, a former German Minister for the Environment, travelled to the Balkan on behalf of the European Union to settle a dispute between Kosovo and Serbia over the local power distribution lines. Since the various national power grids are coupled, this local dispute led to problems with frequency variations in the whole European Union ("Duitse gezant naar Balkan over stroomdip", 2018).

Load Shifting and Management

Load management is needed to prevent overloading of the transmission lines, while maintaining the distribution of electricity. *Critical Surplus of Electricity Production* occurs when electricity production simultaneously exceeds the demand in a given area and the capacity of the power grid to enable its export (Lund & Münster, 2003). Failing to perform *load management* can cause the overload of the transmission line, permanently damaging or destroying it. The systems require reaction times of minutes up to an hour and a larger energy capacity to enable a longer release of electricity.

Q-Set 1: Performing Load Management.

Energy Management

This is the availability to provide year-round energy on demand. The advantage of fossil fuels is that they can be easily stockpiled for immediate access and conversion to electricity and are easily transportable for import. Since electricity cannot be stored, stockpiling renewable electrical energy for year round access is impossible (Evans et al., 2012). This creates a daily and seasonal mismatch between demand and availability of electricity. Energy Management thus requires the ability to store a very large amount of energy and the availability to supply high levels of power.

Q-Set 1: Performing Energy Management.

Current Network Balancing Mechanisms

Multiple balancing systems are discussed in literature. The most often used are (Weeda & Gigler, 2018):

Demand Side Management is the adjustment of the end-user's energy demand through technological and behavioural methods. A technological solution is the use of controllable loads such as electrical vehicles.

This would enable the spread of electricity demand in time. From a utility point of view, this flexibility on residential level would support balancing the grid. These benefits are however not tangible for the end-user. Furthermore, the marginal costs of electricity provided by the grid does not justify the high investment costs. A behavioural solution can be achieved by offering flexible tariffs. However, pilot projects using flexible tariffs led to the shifting of peak loads to another point in time (Dell & Rand, 2001; Gottwalt et al., 2011; Vazquez et al., 2010).

Area Spreading. This is the spreading of electricity over a bigger area. It requires strengthening the power grid between various regions. According to Dell & Rand (2001) and Koç (2015) this would be a very costly solution. Furthermore, this solution is not viable. This is because multiple regions endure simultaneous surplus and shortages (Lund & Münster, 2003).

3.2 The Anticipated Roles and Benefits of Storage

The implementation of storage application in the power grid is to decouple electricity generation and demand, both in term of time and space. Next, the benefits of storage applications within the supply chain of electricity are discussed. Furthermore, various scenarios are introduced, describing their anticipated capabilities. This clarifies the difficulties caused by the strict separation of responsibilities in and between sectors. First, the difference between *storage* and *conversion* is explained.

The Storage versus the Conversion of Electricity

Despite the term storage, electricity is very hard to store. He et al. (2011) describe its operation as: *'The function of electricity storage lies in a bidirectional transformation process: first electricity is transformed into a storable form of energy at certain efficiency, and second the stored energy is recovered rapidly into electric energy with certain losses in case of need'*. As such, electrical energy is seldom actually stored, but converted in a storable form of energy. However, literary sources distinct between the description's *storage* and *conversion* of electricity. This distinction between the two is applied in this report as well and is as such:

Storage technologies, or *direct storage*, are defined as *Power to Power* applications. Electrical energy is converted into a storable form of energy and reconverted back to electricity on demand. This is done by a single closed system.
Conversion technologies, or *indirect storage,* are defined as *Power to X* and *X to Power* applications. Electricity (electrons) is converted into an energy-carrier (molecules). This energy carrier can be used in various applications, including the re-generation of electricity. Both steps, Power-to-X and X-to-Power require a separate system. Examples of energy-carriers mentioned for these applications are hydrogen and methanol.

Benefits of Storage Applications for Conventional Generations

The current usage of base-, intermediate- and peak-load power plants is previously described. As a result, most countries tend to have surplus of generating capacity. This leads to the sub-optimal use of resources. To quote Evans et al. (2012, p. 4142), '*maximum power demand may only last for several hours each day, which traditionally has led to over-designed and expensive power plants made to run at a steady state production much higher than the average base load.*' Implementing storage can enable power plants to generate electricity at the most efficient state of operation while meeting the fluctuation in the immediate demand (Dell & Rand, 2001). Furthermore, storage applications can eliminate voltage sags and surges by providing an *Uninterruptible Power Supply* (UPS). This reduces the need to maintain a *spinning reserve* as reserve capacity.

Q-Set 1: To increase the efficiency of fossil production.

Benefits of Storage on Renewable Generation Levels

The integration of renewable electricity generation requires changes in system management to ensure power quality and reliability. The introduction of new technologies and strategies, such as weather and electricity generation forecasting and modern power electronics, can mitigate to some extent. This will however not enable a significant increase of renewable generation. As such, renewable generation is often curtailed, both in times of significant generation and during unfavourable market conditions (Barnhart et al., 2013)

Jorgensen and Ropenus (2008) state that an average power grid can absorb the variation of power quality associated to renewable electricity through the ramping of conventional power plants. However, this is limited to a ratio of 20% renewable electricity generation. In absence of storage, the further integration of renewable electricity leads to costly grid reinforcements. Furthermore, it reduces the *load factors*, as both transmission and distribution networks are built to handle peak powers (Dunn et al., 2011). The *load factor* is the ratio between the actual load and the maximum acceptable load. Furthermore, the *capacity factor* of renewable electricity generation is low. This is the ratio between the actual output of electricity compared to the theoretical output and, in case of renewable electricity, depends on the prevailing weather conditions. The low factor leads to the provision of back-up capacity by conventional peak-load power plants in order to guarantee the supply of electricity. Vasquez et al. (2010), estimate this required back-up to be to be 2 – 4% of the theoretical output of renewable electricity generation. This estimate is calculated considering a ratio of 10% renewable electricity penetration in the aggregated power generation. It is expected to increase at higher penetrations. Therefore, the increase of renewable electricity production does not lead to a comparable decrease in fossil-based generation.

Q-Set 1: To stabilize the variable output of renewable electricity.

Scenario's for the Implementation of Storage and Conversion Applications

Figure 8 to ***Fout! Verwijzingsbron niet gevonden.****0* illustrate the most extreme possibilities with regard to the usage of storage applications in the power grid.

Figure 8 illustrates the current Dutch *Power Grid*. The network managers perform real time balancing through distribution, the use of capacity reserves and the curtailment of electricity production. According to Van Wijk and Verhoef (2014), the *full chain efficiency* of the Dutch power grid is reducing due to the societal developments, as described in chapter 1.

Figure 9 illustrates the role of storage systems in the power grid. The systems are expected to assimilate electricity, regardless of its quality and prevailing demand, in order to enable its controllable release within the grid. Another option involves solely the absorption of electricity. The energy is than released in other sectors. Storage is thus used to decouple supply and demand in terms of time.

Q-Set 1: The separation of the production and usage of electricity in terms of time.

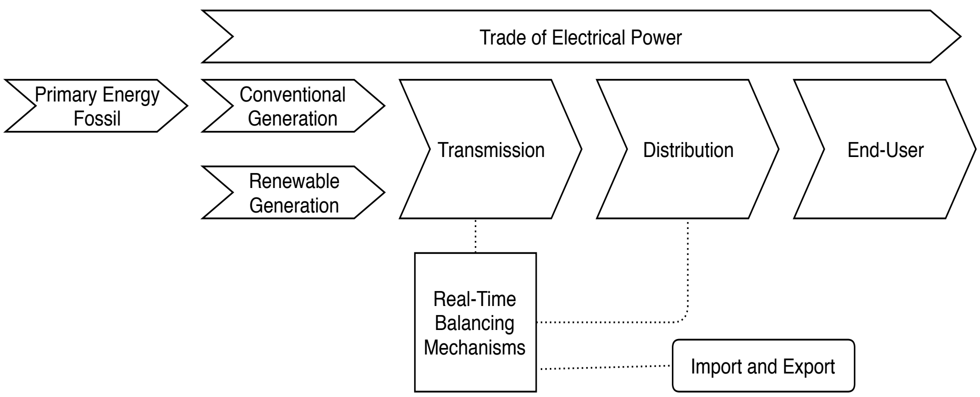


Figure 8 - The Current Situation in the Grid

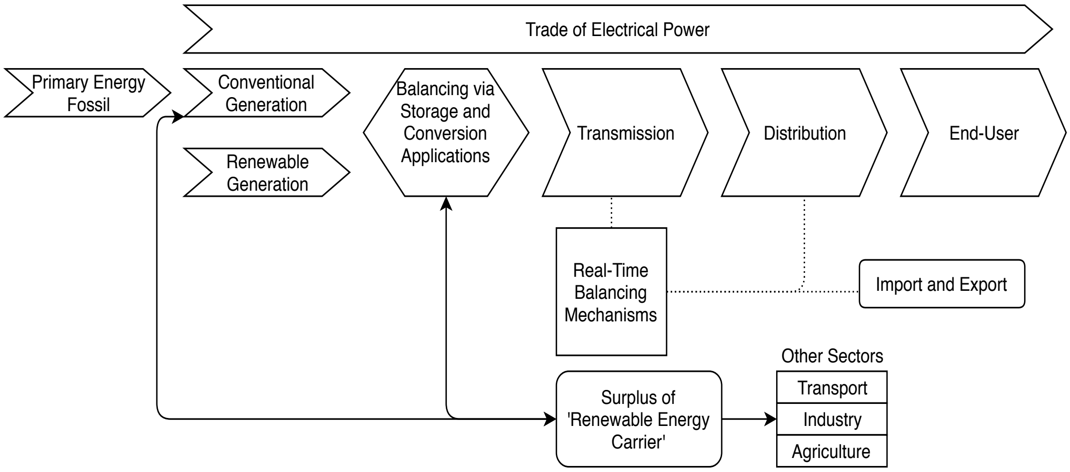


Figure 9 - Implementation of Storage in the Power Grid only

Figure 10 shows the scenario in which storage applications are used to integrate the various energy infrastructures and to enable the flow of energy between sectors. De Boer et al. (2014) and Oldenbroek et al. (2017) suggests Power-to-X as a way to absorb energy surpluses in the power grid in order to shift part of the load to the natural gas grid. The Dutch innovation agenda 2016 – 2019 emphasizes that 98% of the Dutch end-users are connected to the gas grid and that the network is, to the utmost extent, capable of absorbing alternative gasses ("*Met gas naar een klimaatneutraal energiesysteem—Innovatie en Kennisagenda Gas 2016—2019*", 2015). As such, storage is used to decouple supply and demand in terms of time and location. Furthermore, it integrates two energy infrastructures.

Q-Set 1: To enable the integration of energy networks, such as gas and electricity.

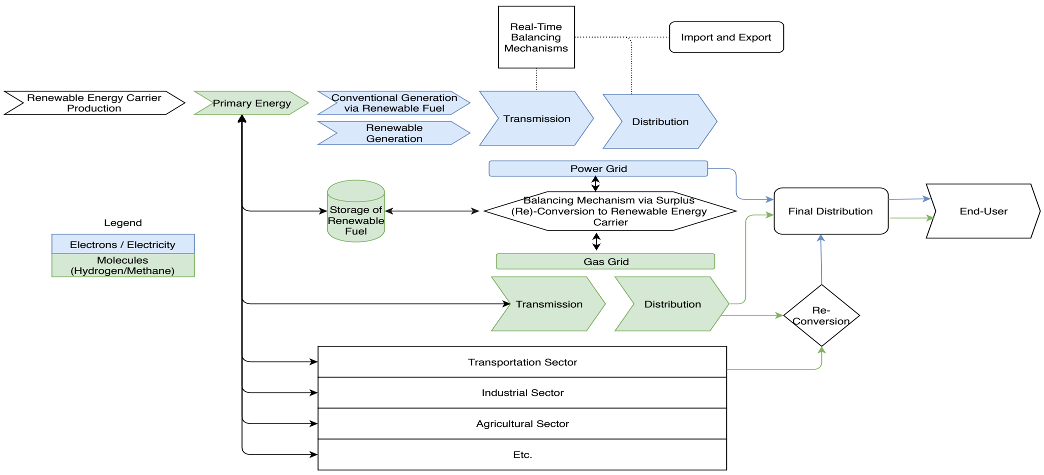


Figure 10 - Full intersectoral integration of Storage and Conversion

The conversion of electricity to a molecular energy carrier illustrates a holistic view on the development of energy related sectors. This energy carrier could be used to substitute fossil-based materials. This includes, but is not limited to, its usage in the generation of heat, as feedstock for the chemical and agricultural industry and as fuel in the transportation sector (Dell & Rand, 2001; Hall & Bain, 2008; Hoogma, 2017; Kelly et al., 2009; Kyriakopoulos & Arabatzis, 2016; van der Meijden, 2017; Weeda & Gigler, 2018; Wiersma, 2017).

Q-Set 1: To enable the integration of the electricity sector with other sectors (for example the transport sector).

Van Wijk and Verhoef (2014) suggest the further development of this scenario. They propose the large-scale production of an alternative energy carrier through renewable electricity generation in order to substitute fossil fuels altogether. The best locations can be used to develop large renewable energy generation sites. Subsequently, the generated energy carrier can be transported globally. This would enable the environmentally friendly generation of electricity using controllable conventional power plants, thereby greatly reducing the grid imbalance at the source. Despite the additional losses due to the conversion of *primary energy* to create an *energy carrier,* the efficiency of the Dutch power grid would increase from 40% to 45%, based on current technology (Boeters, 2018; van Wijk & Verhoef, 2014).

Q-Set 1: To enable the substitution of fossil fuels through conversion.

Q-Set 2: The technological possibility with regard to the substitution of fossil fuels.

Renewable energy methods have the potential to generate around 35 time the world energy consumption. This requires 10% of Australia's inner land when using solar power or 1.5% of the Pacific Ocean using wind energy (Johansson & Turkenburg, 2004; Oldenbroek et al., 2017; van Wijk, 2017).

The company Vattenfall applied the benefits of conversion in the design of the *Magnum* power plant. This plant provides balancing capacity through the conversion of surplus of electricity to hydrogen. The hydrogen is either sold as feedstock to other sectors, or is reconverted to electricity (Haspels, 2018).

Finally, Hall and Bain (2008) offer an alternative view on the use of storage applications by claiming it can offer an alternative form of electricity supply to the billions of people worldwide deprived of access to the power grid. This enables the distribution of good while providing significant market opportunities for industry.

Next, the influence of the external forces associated to the PESTLE analysis as found in academic literature is discussed.

3.3 Political and Regulatory Factors Influencing the Implementation of Storage

The report so far deducted how policy, regulations and market forces led to the fragmentation of the Dutch electricity sector. This is not solely a Dutch problem. The lack of a formalized European energy plan resulted to regulatory and political development on national levels (Johansson & Turkenburg, 2004). The trade of electricity, however, is done on European levels. The current fragmentation in the market led to market and system failures. National policies and investments led to competition between renewable and fossil-based electricity generation in some countries, and thus to large differences in renewable electricity generation between nations. In consequences, European energy flows are very large in comparison with the actual energy demand. This led to high volatility in the prices of renewable electricity, negatively affecting the market value of renewable generation plants (2004).

Q-Set 2: The "level playing field" between renewable and fossil electricity production.

Q-Set 1: To Limit large fluctuations in electricity prices.

When market fragmentation lead to the lack of common objectives, formal and informal rules surrounding the technology may hamper markets expectations to deliver on public goods. This calls for the intervention of a change agent (Rogers, 1983).

Governmental policy can steer development by taking on the roles of financer, leader, stimulator and facilitator. Doing so, government can:

Reduce some of the investments and uncertainties;
Provide long-term security for investors;
Guarantee access to the market and a certain market size;

Guarantee a certain price;
Guarantee a capable infrastructure;
Limit and deal with local and societal resistance;
Provide unambiguous goals and long-term vision.

The role of policy is thus to act as *initiators* of change, while financial institutions should be considered as *instruments* of change. Therefore, they require viable business cases (van Dril, 2018; Johansson & Turkenburg, 2004; van Swaay, 2018).

Q-Set 2: The presence of investment capital.

The guidance of policy and regulations can be opposed by market forces This happens when regulations are not consistent between sectors and geographically dispersed markets or in absence of a common and clear end-objective. Furthermore, market intervention can lead to the loss of technology leadership of some stakeholders. Finally, governments refrain from choosing a technology in order to create diversity and innovation through competition. The competition in the energy market is however not solely based on the economic value of energy, but on its environmental benefits. This creates uncertainty for companies faced with significant investment decisions, since these will determine the structure of the infrastructure and the composition of the marker for decades. It can therefore be argued that the choice of a standard is needed (Johansson & Turkenburg, 2004,; Kern & Smith, 2008).

As previously discussed, the scrutiny of the regulatory framework in the Dutch electricity sector raises the question whether the current stakeholders can legally implement storage applications. This is substantiated by research by the *American Physical Society*, consisting of members from academia, national laboratories and industry. In 2011, this society presented an extensive report on the integration of renewable energy including the role of storage applications (Crabtree et al., 2011). The following are quotes taken directly from this report:

'Utility renewable energy investments are typically assessed from regulatory, project finance, and technical perspectives. The regulatory assessment focuses on ensuring utility compliance with renewable portfolio standards (RPS) and that costs are kept within prudent limits. While these conventional views are important for investors, utilities, regulators and ratepayers, they do not fully capture the set of benefits that a renewable energy investment can deliver beyond the boundaries of a given project, such as the physical benefits of transmission and storage and the organizational benefit of developing an integrated picture of the grid' (2011, p. 5).

'From a regulator's perspective, the energy provided from the batteries during the peak period may look like generation. Some states such as New York categorize storage as 'generation,' and hence forbid transmission utilities from owning it (2011, p. 4). '

The historical development of policy and regulations thus resulted in the same fragmentation of the electricity market in the U.S.A. and created comparable challenges in the development of a viable and legal business case for storage applications.

Q-Set 2: The legal separation between production, trade and distribution of electricity.

Q-Set 2: The separation between public, semi-public and commercial responsibilities in the electricity sector.

'If the market reacts, substantial profits can be made from investing in storage application' (Lund & Münster, 2003, p. 72). The following paragraph describes the economic opportunities and barriers, as perceived by academic literature.

3.4 Economic Factors Influencing the Implementation of Storage

The economic value of storage applications in the power grid can be grouped in the following categories (González et al., 2004; Kyriakopoulos & Arabatzis, 2016; Vazquez et al., 2010):

The Energy Value

These are the costs savings achieved by enabling the usage of renewable electricity generation compared to fossil-based generation due to the lower marginal costs of generation. According to Lund and Münster (2003), in 2003, an average of 16 million Euro of renewable electricity value was lost in Denmark due to the incapability of the grid to facilitate its trade. In addition, additional costs were made to compensate fo the curtailment of this electricity using conventional generation. Between 2007 and 2012, an average of 17.1% of renewable electricity generation was lost in Texas, USA (Barnhart et al., 2013).

The Generation Capacity Value

These are the cost savings by preventing the development of back-up fossil generation plants due to the low capacity factor of renewable generation sites. Furthermore, it includes the cost savings of enabling the avoidance of operational reserve capacity provided by conventional generators.

Transmission and Distribution Network Value

These are the savings obtained from the prevention of enforcing the power grid. In Denmark, the generation of wind-powered electricity would require investments up to 1.2 billion euro in the grid. As previously discussed, this is a fraction of the estimated costs in 2019 in Germany. The investment in storage is deemed a cheaper and technologically more effective solution than enforcing the power grid (Lund & Münster, 2003).

Q-Set 2: The profitability of balancing via storage with respect to fossil production.

According to Hé e.a. (2011) however, the implementation of storage application is only profitable if it can capture its full economic value by providing system services for all stakeholders involved in the sector. This is complicated due to the fragmentation in the market.

Furthermore, it is hard to provide insight in the financial gains of storage. The costs and benefits vary significantly due to uncertainties attributed to the following values:

Marginal costs

According to Jorgensen and Ropenus (2008), the estimated price for the generation of 1 GJ of energy stored in hydrogen through the conversion of surplus electricity varies greatly. Three different studies estimated the costs ranging between €16, - and €35, -. The difference in the estimated capital expenses was 40%, while the variations in operational costs were 600%. The biggest uncertainties in prices were however due to the uncertainties with regard to taxes. A Dutch study calculated the price of 1 GJ of hydrogen, generated via the conversion of wind-energy, to be of €110, -. Furthermore, it claims future technologies would reduce the price to €25,- (Oldenbroek et al., 2017). In comparison, the price of 1 GJ of energy stored in natural gas was €26,15 in 2019 (Vattenfall.com, 2019).

Investment and operational costs

Academic papers all claim that the initial investments costs are barriers with regard to the implementation of storage applications. However, the estimation of the operational costs varies greatly. This leads to pay-back periods varying between 6 and 43 years, for comparable systems. However, all sources are consistent stating that the prices of flexibility through hybrid systems will drop much faster than that of conventional systems, leading to competitive prices in the near fututure (Haspels, 2018; Türkay & Telli, 2011; van der Stelt et al., 2018).

Financing costs

The unfamiliarity of hybrid systems leads to high interests on loans. In combination with relatively long building times, this results in the cheaper option becoming more expensive (Kyriakopoulos & Arabatzis, 2016).

Q-Set 2: The financing costs of storage.

Q-Set 2: The CAPEX of storage.

Q-Set 2: The OPEX of storage.

Next, the benefits and limitations of storage applications are discussed from the point of view of technology.

3.5 Technological Aspects influencing the Implementation of Storage

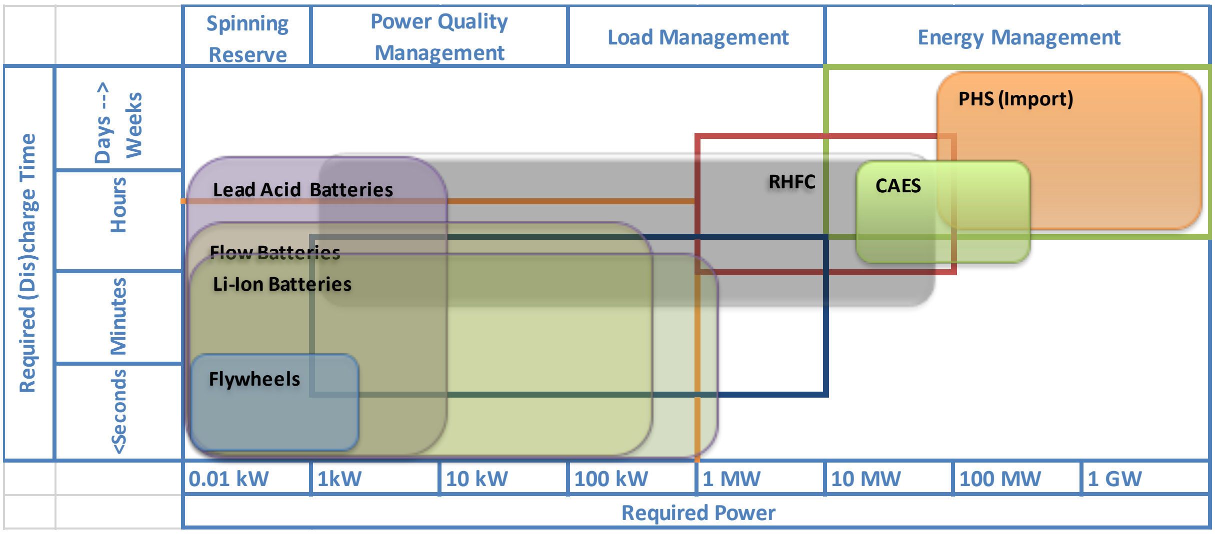
There are multiple technologies, or, as Dunn et al. (2011) put it, '*a battery of choices*', available to store electrical energy. Each have their own benefits and limitations based on their key-parameters. An extensive overview of these technologies and their parameters is given in *Appendix 3* and later summarized in *Table 2 - An overview of Key-Parameters of Storage Applications*.

This paragraph is limited to the illustration of the capacity of the main storage application to perform the system services required to balance the power grid. The system services are previously described in section 3.1.

The Application of the Storage Technologies in the Various System Services

Figure 11 shows the capacities with regard to power and energy of the various storage systems compared to the requirements of systems services. It confirms the limitations of storage applications previously discussed from the point of view of economics. No single energy storage device is currently able to meet the combination of energy and power requirements to execute all system services. Furthermore, it is unlikely that a single system will be found to do so in the near future. Although this can be mitigated by applying a combination of technologies, this would considerably increase the costs. This reduces the competitiveness of creating flexibility through storage applications versus via fuels (Dunn et al., 2011; Vazquez et al., 2010).
The technological development of storage systems is mainly influenced by the lack of qualified personnel. Especially software engineers are required for the development of power management software. A second issue is the availability and development of optimised materials ("*Digitalization and the future of energy storage*", 2019; Evans et al., 2012; Hall & Bain, 2008).

Q-Set 2: The availability of raw materials for storage.



Legend of Rectangles	
Orange Border	Local / End-User application
Blue Border	Grid Power Quality Management
Red Border	Grid Load Management
Green Border	Grid Energy Management

Figure 11 - The Main Technologies versus the System Services

Sources: Adapted from (Crabtree et al., 2011; Dunn et al., 2011; Evans et al., 2012; Hall & Bain, 2008; Kyriakopoulos & Arabatzis, 2016; Lund & Münster, 2003; Vazquez et al., 2010)

3.6 Societal and Environmental Factors Influencing the Implementation of Storage Applications

Multiple statements describing societal and environmental factors were deducted in the previous chapter. No additional statements were deducted from the academic literature. The following factors are however consistent in both academic and non-academic literature:

Opportunity: The societal recognition for environmental concern.
Barrier: The societal focus on personal costs.

The first factor leads to the call to accelerate the integration of renewable electricity. This would require the implementation of balancing mechanisms such as storage applications. The second factor thwarts both the development of a business case for such systems in the market environment and, alternatively, the investments by government (Barnhart et al., 2013; Dell & Rand, 2001; Gottwalt et al., 2011; Johansson & Turkenburg, 2004).

The previous chapters provided a summary of the implementation of storage applications. The emphasis was placed on their role in the power grid. A set of statements were deducted to execute a Q – Methodological research. The following chapters describe the execution of the research and the associated results.

4. Q-Methodology

4.1 Q – Methodology: A Brief Explanation

Q-Methodological research was first introduced by William Stephenson in 1935, in a letter to the journal *Nature*. It is an exploratory technique, designed to produce objective outputs from subjective inputs. The research combines the gathering of qualitative data and intercorrelation via factor analysis to reveal and substantiate the key viewpoints among a group of participants. The method does not prove hypotheses but is deployed to explore complex and socially contested topics from the first-person viewpoints and opinions of the respondents. The end-results are thus substantiated propositions for which consecutive research is needed to come to a verifiable theorem. The method does thus not answer questions like '*Who said what about X?'* but rather *'What is said about X?' (Watts & Stenner, 2005, 2012)*

In its most basic form, Q-Methodology can be described as a derivation or inversion of R-factor analysis. The main aim of R-Methodological analysis is to statistically identify associations of a latent number of variables across a population of persons. Stephenson argued however that these variables do not reflect the various perspectives, or viewpoints, of the individual respondents involved. As such, in Q-Methodological factor analysis, the statistics are not applied to individual or a collection of statements, but to the specific configurations produced by the participants. As such, the factor analysis in R-Methodological studies aims to find correlations in variables with regard to the topic at hand, based on the surveys provided by a sample of respondents. The analysis in Q-Methodological studies is designed to find correlations in the viewpoints of respondents in a sample of variables. (Cuppen et al., 2010; Watts & Stenner, 2005).

Strength and Limitations of Q – Methodology

A big difference between the execution of Q-Methodological survey compared to more traditional measuring instruments such as the Likert scale is that statements are not valued individually but in relation to each other. During the sorting, participants are asked to actively rank *'a heterogenous set of stimuli',* the statements, according to their opinion with regard to the subject at hand. Q-Methodology is based upon the desire of the participants to ascribe meaning to stimuli. As a group of stakeholders will attempt to impose their viewpoints on the set of items given. This ensures the robustness of the research (Watts & Stenner, 2005; 2012). Furthermore, participants are encouraged to provide additional feedback on their choices.

An important part of the Q - Sort consists of the post-sorting interview. Its aim is to gather supporting qualitative information. Respondents are requested to substantiate the way they have sorted their statements, with emphasis on the high and low rankings. Furthermore, they are encouraged to discuss items they found confusing, want to comment upon or missed altogether. This interview is best done both directly after the sorting and after the interpretation of the data. The accuracy of the produced Q-Sort and the subsequent interpretation is thus verified by simply requiring the participants to comment upon them (Den Boer et al., 1994; Watts & Stenner, 2005).

During the subsequent analysis and interpretation, the population of *viewpoints* are described. The combination of the quantitative data derived from the sorting and the qualitative information provided by the respondents is used for this. As such, the method requires a lower sample size compared to traditional quantitative analysis where the aim is to generalize the results over a general population of *people*.

Q-Methodological research is not devised to prove hypotheses. The product of the Q-Factor analysis are statically calculated loadings, or common perspectives, that can be interpreted as a measure of agreement between respondents (Cuppen et al., 2010). Decision making processes are often characterized by (scientific) uncertainties and involve a diversity of conflicting values. Disagreement is often discussed on a general level. The origin of the disagreement is however often on a more detailed topic. According to Watts and Stenner (2005, pp. 85–86), therein lies the strength of Q-method, as: '*Q-methodology entails a focus on subjectively expressed, socially organized semantic patterns. It does not deny communicative pragmatics at microlevel, nor of macrolevel social structures.'* The method aims to provide insight in different positions and opinions towards any topic. This can help the later development and substantiation of hypotheses. To a certain degree, generalization of the interpreted viewpoints can be achieved by repeating the survey within a different, but comparable, population or by executing a follow-up study using a measuring tool like the Likert scale.

A second limitation is that the viewpoints are not necessarily consistent across time. This is however due to the changing views of the participants, and not the method itself. The calculated loadings during the *factor analysis* are considered trustworthy, since these will not differ when re-calculated using the data. This replicability is an important aspect of the reliability of the method. Furthermore, by repeating the same Q–Sort over time, the method can be used to identify these changes in views. For this, the method requires a very careful description of the definitions used in the research (Bouwman et al., 2012; Cuppen et al., 2010; Den Boer et al., 1994; Watts & Stenner, 2012).

4.2 Conducting the Q – Methodological Research

This chapter describes the various stages of research executed for this thesis.

Compiling the Concourse

The starting point of Q-Methodological research is the creation of a Q-Set with the support of a concourse. The concourse is a substantiated list of the widest range of opinions with regard to the topic of research. In other words, the concourse is to a Q-Set, what a population is to a sample of persons (Watts & Stenner, 2012). The opinions are usually expressed in statements.

There are two ways of compiling the concourse:

Unstructured Sampling: The researcher samples from the whole population, without any pre-defined plan;
Structured Sampling – The researcher starts by breaking down the topic in a number of themes and issues on the basis of theories or observations. Relevant opinions and statements are than sought after in a population of involved actors*. 'A downside is that a representative nature of the sample might be badly damaged if the themes are insufficient, poorly conceived or simply reflect the researcher's view' (Watts & Stenner, 2012, p. 57).*

Den Boer et al. (1994) states that the origin of the statements, whether *naturalistic*, specifically sought after and gathered by the researcher, or *ready-made* does not matter for the method.

The concourse for this thesis is compiled in an unstructured manner. This is done by first collecting any statement associated to the topic from various sources and to perform the subsequent structuring, validation and selection of statements for the concourse in a later phase of the research.

Collecting the Statements

A collection of statements was filtered from various sources in a timeframe spanning between October 2017 and June 2018. These statements are gathered both from literature on previous research and from interviews and discussions performed specifically for this thesis.

First, literature and existing research are actively sought after in various repositories of academic papers and professional journals. This includes the library of the *Delft University of Technology, Google Scholar* and *Web of Science*. The search is executed including but not limited to queries such as *Grid Management, Electricity/Energy storage* and *Power Grid and Balancing.*
This subsequently incited the use of new keywords, such as *Energy Economics* and *policy* and *Critical Surplus of Electricity*, as well as the use of an author's name mentioned as reference in previous papers.
For each search query, the five most cited articles were chosen. The tool *Web of* Sciences is used to prevent the usage of multiple articles with the same original sources. When applicable, the most cited article was selected. This is done to prevent the overrepresentation of any, possible biased, researcher or research group.
Furthermore, multiple statements are filtered from newspaper articles and (consultancy) reports released or found by coincidence during the timeframe specified previously.

Simultaneously, statements are collected via group discussions and interviews during multiple seminars, expert presentations and expert discussions on the topic. These were selected for pragmatic reasons, such as distance and fees.

The first conference was held December 8th to 10, 2017. It discussed the various possibilities of electricity conversion into hydrogen, including balancing mechanisms, on the Dutch island of Goeree-Overflakkee.
The second conference was held April 17th and 18th 2018. It was more general in nature and discussed the anticipated challenges to the energy sector, as well as possible solutions.

The presentations were given on behalf of the Dutch platform on hydrogen, *Op Weg Met Waterstof.nl*.
The first was held October 20th, 2017 and discussed the future expectations of the Dutch Transmission Lines operator, *TenneT*. It set fourth developments to fulfil its task given the anticipated increase of electrification and integration of renewable electricity.
The second presentation, on December 14th, 2017, was comparable to the first, albeit on the future of the natural gas grids from the point of view of the operator *Gasunie*.

As such, data from ready-made sources is used as basis for interviews and discussions with actors involved in the energy sector. In turn the same actors advised on the consultation of new articles, sources and other actors. This process was continued until the point of *saturation* was reached, or the moment no new information or alternative viewpoints could be filtered from a new source of information. This led to an extensive, albeit unstructured, list of statements.

The Selection of Statements for the Concourse

In order to reduce the number of statements and to guarantee a minimum degree of substantiation the following steps were applied:

First, the statements with equivalent scope were combined.
Thereafter, the statements lacking a minumum of two different substantiating sources were deleted.
The number of statements is subsequently reduced by forfeiting the difference between *direct* and *indirect storage* and by forfeiting the difference between *Transmission* and *Distribution Networks.*
Finally, the statements that do not strictly align with the research scope are removed.

The remaining and doubtful statements were then discussed with a consultant involved in the energy sector (bakboordconsult.nl), at whose recommendation seemingly incorrect or irrelevant statements were deleted.

Two examples of statements:

1) Implementing storage facility is needed to maintain the equality constraint.
2) Policy is needed to level the price of fossil based and renewable based electricity.

One can see the statements include certain orientations. The first discusses possible technologies while the second is more oriented towards regulatory aspects. The final Q-Set of statements filtered from the concourse should be balanced with regard to these orientations. Furthermore Cuppen et al. (2010), emphasizes that in the final Q-Set, each orientation should be represented by an equal number of participants.

Developing the Q – Set

The Q-Set is the final list of heterogeneous statements representing the wide range of opinions filtered from the concourse. Each individual statement should make its contribution to the set and the items should sit side by side without gaps or overlap. This is to make sure the Q is not biased towards some particular viewpoints.
Although there is no pre-set amount of statements in a Q – Set, on average, 40 to 80 statements has become the "house standard". The final Q-Set can originate from any number of sources. The exact nature of the sampling is of little interest as long as it justifies the representation of the various relevant opinions and with regard to the research question. (Bouwman et al., 2012; Cuppen et al., 2010; Den Boer et al., 1994; Stephenson, 1953; Watts & Stenner, 2005, 2012)

According to Watts and Stenner (2012), there is no correct way to generate the final Q –Set. It should however adhere to the following requirements:

1) The statements should not contain technical and complicated terminology and should be designed to accommodate the level of knowledge of the respondents.
2) The statements should not be double-barrelled, for example: *'Storage is needed for security and for economic reasons*.'
3) The statements should not be negatively expressed, for example: *'Storage should not be used for..'*.
4) Multiple statements should not express opposites. For example: *Statement 1: 'Storage will increase the robustness of the power grid'* while *Statement 2: 'The integration of extra systems in the grid, such as storage, will increase the number of malfunctions.'*.
5) It should provide good coverage in relation with the research questions.
6) The dimensions should be chosen to fit the problem statement.
7) The dimensions should be represented by an equal amount of statements.

The demands 1 to 4 are addressed by submitting a sample of statements for review to actors involved in the sector. Requirement 5 is met by developing two different Q-Sorts and Q-Sets to provide the necessary coverage to represent all research (sub)-questions. Subsequently, a PESTLE analysis is used to meet demands 6 and 7. As such, the statements are structured to equally represent the topics of *Political, Economic, Societal, Technological, Regulatory (Legislation)* or *Environment*al factors influencing the implementation of storage application. The statements in the concourse that are not relevant to the research question of either Q-Sort 1 or Q-Sort 2 are deleted.

The next step is the design of the distribution in which the statements are to be sorted by the respondents.

The Form of the Q-Sort

The process of sorting the statements by the respondents can be facilitated by committing to a forced distribution. A forced normal distribution is often chosen for the sake of simplicity. Numbering from negative value to positive ones, via zero, in a symmetrical manner is preferred. This reflects people's point of view the best, as most feel very strongly in favour or against some statements. As such, the zero is not a neutral point, but a meaningful centre around the level of association with a statement is set. As participants can get upset when forced to rank certain statement negatively or positively, it is important to clarify that the order is important, and not the exact value attributed to each statement as such. (Watts & Stenner, 2012).

The slope of the distribution is important to help participants feel comfortable. A steeper distribution is recommended for unfamiliar topics and a flattened distribution for straightforward ones. Furthermore, a 9-point scale is suggested for 40 items or less, an 11-point scale for 40 – 60 items and a 13-point scale for 60 items and above(2012). The Q-Sorts for this thesis are developed on a 7-point scale. This is due to the number of statements in both Q-Sorts, and the choice to approach a forced normal distribution as best as possible.

Define the P – Set

The selection of participants is an important aspect of Q-Methodology. The participants should have well defined and relevant opinions in relation to the topic of investigation and the aggregated constitution of the P-Set should strive to include all-possible points-of-views (Cuppen et al., 2010; Watts & Stenner, 2005, , 2012). Cuppen et al. (2010) argues against the sole use of either random or stratified random sampling. The first assumes an even spread of relevant information over the population while the second does not guarantee a correct representation of perspectives. Therefore, literature on Q-Methodological research claims that the selection of participants should be done in a strategic way while pragmatic reasons suffice during the development of the final P-set. Any stakeholder is assumed to have an interesting or pivotal opinion. It is accepted that the set evolves on the go, via snowballing and word of mouth (Den Boer et al., 1994; Watts & Stenner, 2012).

According to Watts and Stenner (2012), a large numbers of participants is not required. The most effective group is between 40 and 60 individuals, however effective studies can be done with far less participants. The emphasis on the selection should be to include all possible viewpoints.
The minimum number of respondents should match the number of perspectives for the research and topics at hand. It is best to have four to six respondents with a relatively high factor loading on each factor. However, it is unknown in advance how many factors will emerge from the statistical analysis or how the individual participants will load on them. As such, the best is to have enough participants to enable each

perspective to be represented from the point of view of each element. As a rule-of-thumb, the number of respondents should not exceed the number of statements in the Q-Sorts, which is 36 based on Q-Sort 2 (Cuppen et al., 2010; Den Boer et al., 1994; Watts & Stenner, 2012).

For this thesis, respondents are strategically chosen to evenly represent the elements of the *Ecosystem* affiliated to the electricity sector as shown in *figure 9.* Furthermore, special care is taken to include *outsiders* and policymakers. The latter is done in order to create an heterogenous group of respondents. This increases the effectivity of Q-Methodological research, since such a group shows more divergent thinking than a homogeneous group and will thus more likely provide new insights than dominant viewpoints (Cuppen et al., 2010).

For pragmatic reasons, the respondents are selected from the following, pre-existing, groups:

- The Supervisors and presenters participating in the *Working Group on Hydrogen* at Delft, University of Technology (November 2017 – June 2018).
- The group of speakers and invitees of the conferences.
- The common factor during the conferences was the absence of policy makers. The third group therefore consists of the spokesmen on Energy from the political parties represented in the Dutch *House of Representatives* in October 2018.
- Respondents were invited to forward the survey to relations with knowledge on the topic.

The respondents are invited to carry out two Q-Sorts, both distinguishing between two opposite dimensions.

Q-Sort 1 presents statements describing the various roles attributed to electrical storage applications. The respondents are asked to sort them according to their level of conformity per statement: agree versus disagree.
The second Q-Sort describes various institutional factors influencing the adaption of Electrical Storage. The statement are sorted according to the perceived level of obstruction for the implementation of storage applications: barrier versus opportunity.

Therefore, the aim was to have a minimum of two respondents per dimensions in each of the 12 defined elements. This led to a minimum of 24 respondents in order to match the possible number of perspectives. Taking into account a response rate of about 30% for mail questionnaires, as mentioned in Sekaran and Bougie (2016), the aim was to send a minimum of seven invitations per element.

A summary of the final numbers and composition of invitations is given in *Table 2 - The Response Rate*. It includes a summary of the response rate. A detailed list of respondents selected for the P-Set is available on request.

Table 2 - The Response Rate

	Numbers of:											Respons Rate	
	Invitations	Positive Reactions / Surveys sent		Negative Reactions		No Reactions		Not Delivered		Completed Surveys	Unknown or Lost	Total	On surveys sent
Population	**#**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**#**	**%**	**%**
Policy	9	0	0%	3	33%	5	56%	1	11%	0	0	0%	0%
Energy Company	4	3	75%	0	0%	0	0%	1	25%	1	2	25%	33%
Electricity Generator	4	0	0%	0	0%	3	75%	1	25%	0	0	0%	0%
Energy Trade	5	2	40%	0	0%	1	20%	2	40%	0	2	0%	0%
TSO	4	2	50%	0	0%	2	50%	0	0%	0	2	0%	0%
DSO	7	4	57%	0	0%	1	14%	2	29%	1	3	14%	25%
Scientific Organization	7	2	29%	1	14%	1	14%	3	43%	0	2	0%	0%
Financial Institution	2	1	50%	0	0%	0	0%	1	50%	0	1	0%	0%
Lobby	2	1	50%	1	50%	0	0%	0	0%	0	1	0%	0%
Consultancy	4	3	75%	0	0%	1	25%	0	0%	2	1	50%	67%
End User	4	3	75%	0	0%	1	25%	0	0%	1	2	25%	33%
Other / Outsider	4	3	75%	0	0%	0	0%	1	25%	1	2	25%	33%
Total	56	24	43%	5	9%	15	27%	12	21%	6	18	11%	25%

In summary:

1) A total of 56 invitations were send, of which:
   - 24 (43%) invitees responded positive to participating in the survey and;
   - Five (9%) invitees declined for various reasons.
   - The remaining 27 invitations were either not delivered or not responded upon.
2) The initial aim of sending a minimum of seven invitations per sub-population is not met.
3) The composition of reactions shows that:
   - The aim to include a minimum of two reactions per sub-population is not met.
   - The aim to evenly distribute the reactions and executed surveys over the sub-population cannot be met. The absence of positive reaction from policymakers and scientists is disappointing.
4) The composition of positive reactions (24) does however show an acceptable number of surveys, had the problem of storage not taken place. Eventually:
   - A total of six surveys were received and;
   - A total of 18 surveys were either not executed or lost altogether.
5) The final of six surveys constitutes a response rate of 11% compared to the total number of invitations send and a response rate of 25% compared to the number of surveys send.

Execution of the Survey

The survey was executed digitally through the use of software accessible via http://qsortware.net. The participants were requested to do the following:

Fill in a questionnaire on the necessity of storage applications and on the responsibilities of various stakeholders in the various phases of initiation, implementation and adoption.
Thereafter, to carry out Q-Sort 1, illustrating their point of view on the role of such applications.
Subsequently, to sort the statements of the second Q-Sort. This is to investigate their point of view on the opportunities and barriers for the implementation.
The last questionnaire focusses on the timing for the implementation of storage applications.
Finally, the respondents were requested to provide personal data.

The first questionnaire has a dual purpose. It provides potentially valuable qualitative information to substantiate the later interpretation of the statistical analysis, and also serves to funnel the participants from general questions to the ones who require more active involvement, in this case the Q-Sorting.

The process of the Q-Sorting is done in three phases:
First, the respondents are requested to divide the set of statements in three provisional categories, namely stating sentences to which respondents agree, disagree or feel indifferent about with regard to the question and subject at hand.
The next step is the actual ranking of the statements. The respondents are asked to start attributing the higher scores to the statements they agree with. This is done by placing them in the right part of the forced distribution. Subsequently the statements describing sentences they disagree with are sorted in the left part of the distribution and finally the 'ambivalent statements' are sorted in the middle part. The boundaries on the distribution between the categories are to be saved.

The first Q-Sort requires the distribution on level of agreement of 16 statements, on a 7-point scale, with regard to the question:

'According to you, what is the necessity to implement electrical storage and conversion applications in the power grid?'

The respondents are asked to perform the sort on the dimension of perceived necessity, attributing low scores to the potentials of storage they deem the least relevant and high scores to the statements stating potentials they consider important.

In Q – Sort 2, the respondent's sort 36 statements on a 7-point scale, with regard to the question:

'According to you, what is currently an opportunity to implement electrical storage and conversion applications in the power grid?'

The sorting is done similar to Q-Sort 1, albeit with different statements and on the dimension of opportunities.

The use of a digital survey led to a lack of interaction normally sought after in the post-sorting interview. Although the respondents were asked to provide additional information after the sorting, the possibilities of the tool used for the survey were limited. This reduces the efficiency of the research, as the provided feedback is limited and there was no way to discuss ambiguities.

Finally, the personal information, or classification data, provided in the last step was expected to facilitate the illustration of the distinctive views of the various group of stakeholders.

4.3 Statistical analysis

A statistical analysis is applied to the specific configurations of statements produced by the participants. Doing so, the method finds factors the participants load to via statistical calculations. This loading is later interpreted and substantiated by the ranking of individual statements and backed-up by the additional, qualitative, comments given by the participants. The loadings and their interpretation are the product of the research. As a rule of thumb, a Q-Sort leads to 2 – 4 perspectives, or one perspectives per 6 -8 respondents (Cuppen et al., 2010; Watts & Stenner, 2012).

The analysis starts on a very general level, exploring levels of agreement and disagreement between respondents. It ends with a detailed distinction between the groups of respondents. This includes the illustration of the various perspectives on the subject, a description of these perspective and the delineation of the level and cause of the (dis)agreement between the different groups.

Step 1: Exploration on General Level

The first step aims to explore cohesion in the data on a general level. Since the respondents are the variables in Q-Methodological research, this cohesion in certain way generates a first idea on the agreement and disagreement of respondents. As such, the first matrix obtained in the analysis is the correlation matrix, showing the relationships between the individual Q-Sorts (Watts & Stenner, 2005). Since the respondents are the variables, the correlation matrix differs from other quantitative research. 'Normally' the horizontal rows of a data-matrix contain the scores of the respondents on each individual variable. In a data-matrix for Q-Research, the axes are inversed. Although seldom mentioned in literature on Q-Methodology, it is also beneficial to look at the distribution of absolute scores given by the respondents and to compare this with the correlation matrix.

Step 2: Extracting the Factors

The second step of the analysis involves the extraction of factors. These are perspectives that statistically represent the viewpoints on the topic at hand. After subjecting the correlation matrix to factor analysis, one obtains a matrix showing the factors to which participants load. Participants can load on comparable factors, although they have very different Q-Sorts (Den Boer et al., 1994; Watts & Stenner, 2005). The factor analysis for this study is done using *Principal Component Analysis (PCA).* According to Watts and Stenner (2005)., this provides very satisfying results.

The result of the analysis is a set of statistically defined factors, representing perspectives, including their eigenvalues and their relative and cumulative percentage of explained variance.

Step 3: Explore the Separation between Factors

The next step of the analysis is the *Factor Rotation*. By calculating a better, or the best, fit of the data, the rotation enables to find the distinguishing statements and their mutual relationships leading to the calculated factors. This enables to substantiate the perspectives of the respondents, described in step 4.

For the analysis, the varimax rotation is used. This provides the mathematically best solution and is often used in combination with *PCA.* According to Watts and Stenner, this combination provides very satisfying results as long as the researcher does not solely focus on the mathematics. An equal amount of attention is required for the substantiation of the statistical findings using the qualitative information provided by the participants (2012).

It is important to consider how much factors to keep for rotation and for further analysis. For this thesis, the initial selection is done by applying the Kaiser-Guttman criterion and the requirements set by PQMethod, the program used for the analysis.

Step 4: Interpretation of Perspectives

The first three steps depicted above lead to a selection of perspectives. It also highlights the respondents sharing these perspectives and the associated statements. These steps are mainly statistical in nature. The final step of the analysis is thus to interpret these factors. In short, *what* is the common perspective and *how* does it distinct from the other various perspectives.

For this analysis, the data provided in the first steps is used, as well as the qualitative data provided by the respondents. Furthermore, two final statistical calculations are made to provide additional statistical information to compare the perspectives.
First, a correlation matrix between Factor Scores is made. This helps to interpret the level of equality between the perspectives. Thereafter, the Z-Scores are calculated, and the *Factor Arrays are* created.

The Z-Scores are loaded averages of the values given to each individual statement by the respondents loading on a particular factor. These scores are computed to adhere to the scale of the distribution used for the Q-Sort. As such, high Z-Scores represent statements positioned, on average, in the right part of the distribution. Applying these scores in the Q-Sort would result in a loading of 100% to the affiliated perspective.

The following *Factor Arrays* are made to highlight the statements that form the perspectives:

Characterizing factors – The statements receiving the extreme values, -3 and +3
Distinctive factors – The statements placed at statistically different positions compared to the other factors
Consensus factors – The statements placed at statistically equal positions compared to the other factors
Arrays of Difference – The statements receiving the biggest absolute difference in scores

Both the qualitative and the quantitative nature of Q-Methodology is therefore expressed in this final step. The quantitative analysis provides the separation of the various group of respondents on certain perspectives. Subsequently, the qualitative information is needed to create the narrative, or the actual meaning, of these perspectives. This is done in the following chapter.

5. Results

This chapter describes the outcomes of the survey. It answers *Research Sub-Questions 4 to 6* from the point of view of the six respondents.

5.1 Q-Sort Analysis

As described previously, the survey is executed via the online tool QSORTWARE. The subsequent analysis is done in PQMethod using *Principal Component Analysis* (PCA) and the VARIMAX rotation.

Step 1: Exploration on General Level

The results of the survey are first evaluated on a general level, before looking into detailed statistical outcome. This is to quickly gain a general view but is not leading. It does however provide interesting leads for the further analysis, as the more holistic approach might show more nuances explaining the perspectives.

The *Table 3* and *Table 4* show the aggregated scores attributed to the individual statements for both Q – Sorts. Furthermore, *Table 4A* shows the total scores given to the groups of six statements describing the individual external forces within the PESTLE-Analysis in the second Q – Sort. The ranking shows the popularity of the individual statements within the group, based on total score. Statements with equal score, average value and standard deviation score rank equally. The average value is an indication of the aggregated level of agreement towards a statement. The standard deviation serves to assess the level of controversy between respondents with regard to a statement.

Table 3 - QSORT1 Results on a General

		General			
#	Statements	Ranking	Score	Average Value	STDV
1	The separation of the production and usage of electricity in terms of time.	1	12	2,00	1,26
2	To enable the import of "electrical" energy produced elsewhere.	14	-8	-1,33	0,82
3	To enable the substitution of fossil fuels through conversion.	12	-4	-0,67	2,25
4	To stabilize the variable output of renewable electricity.	8	1	0,17	1,83
5	To increase the efficiency of fossil production.	15	-14	-2,33	1,21
6	To enable handling the greater pressure on the network.	2	11	1,83	0,75
7	To enable the integration of energy networks, such as gas and electricity.	7	2	0,33	1,51
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).	5	3	0,50	1,87
9	To maintain the current reliability to guarantee safety.	4	3	0,50	1,64
10	To maintain the current reliability to enable economic security.	10	-1	-0,17	1,17
11	To maintain the current reliability to maintain the current standard of living.	9	-1	-0,17	0,98
12	To Limit large fluctuations in electricity prices.	13	-5	-0,83	0,75
13	To reduce the energy dependency on other countries.	11	-3	-0,50	1,05
14	Performing Power Quality Management.	9	-1	-0,17	0,98
15	Performing Load Management.	6	2	0,33	0,82
16	PerformingEnergy Management.	3	3	0,50	0,84

General Exploration of Q-Sort 1

With scores of 12 and respectively 11 points, and average values of 2.00 and 1.83, it is clear that:

Statement 1 - The separation of the production and usage of electricity in terms of time, and;
Statement 6 - To enable handling the greater pressure on the network,

are by far the statements considered to describe the most important roles of storage applications. The low standard deviations indicate agreement between the respondents. The higher standard deviation of statement 1 is caused by respondent 3, attributing a score of zero. His qualitative feedback, however, describes that the essence of electricity storage in the power grid is to stabilize the output of renewable electricity production *to 'prevent malfunctioning of the grid'*. Therefore, the overall agreement seems that the main role of storage is to increase robustness of the network.

The respondents agree that the role of storage applications is not to increase the efficiency of fossil fuels. This is deducted from the total score of -14, and average of -2.33, attributed to statement 5: *To increase the efficiency of fossil production.*
However, the feedback provided to this statement suggests this is due to the negative view on fossil energy, and not on the actual benefits of storage. A selection of comments:

> Respondent 4 - *Reducing fossil should be priority number one for the climate. Making its usage more efficient is only tolerating delay.*
> Respondent 6 - *Increasing the efficiency of fossil production only distracts from the ultimate goal of sustainable energy.*

It is notable that despite these comments, the scores attributed to *statements 3 and 4* are relatively low. However, the standard deviations for these statements are high, signalling controversy. The same applies to statement 8. This indicates the presence of distinctive differences in perspectives, and the need to analyse in more detail. But first, the same general evaluation is done for Q – Sort 2.

General Exploration of Q-Sort 2

The statements of Q-Sort 2 are structured according to a PESTLE analysis, grouping six statements for each external force. *Table 4* shows the aggregated scores for the individual statements and *Table 4A* the summation per external factor.

Table 4A shows the respondents consider policy as the biggest opportunity for the implementation of storage applications, while economic factors are considered the biggest barriers. Consequently, five out of six politically oriented statements have positive aggregated scores, and include the highest scoring statement of the Sort, with a value of 12:

> Statement 3 - The political attention with regard to making the electricity sector more sustainable.

Furthermore, the Standard Deviations of statements 1 to 6, suggests that the respondents agree on the positive influence of policy in general. However, when looking into the qualitative feedback provided by the respondents, this positive influence of policy seems to be more *anticipated* rather than currently experienced. Two examples of comments provided by the respondents:

> Respondent 1 - *Policymakers committed to the climate agreement. There is thus a lot of attention and therefore a lot of support.*
> Respondent 6 - *Policymakers are forced to take action.*

The suspicion that the respondents emphasize the *anticipated* and not the *actual policy* is strengthened by the *Standard Deviation of* statement number 4 (1.87), questioning the clarity of the political vision on sustainability. While most respondents attribute positive scores to this statement, respondent 5 ranks it at -3, stating that: *'The political vision is completely missing.'* Arguably, the respondents *anticipate* a clear political vision to be beneficial, but the *current* vision to be inadequate.

Table 4 - QSORT2 Results on a General Level

		General			
#	Statements	Ranking	Score	Average Value	STDV
1	The political attention with regard to the reliability of the network.	9	4	1,00	0,82
2	The political long-term vision of the network.	7	5	1,00	0,41
3	The political attention with regard to making the electricity sector more sustainable.	1	12	2,00	1,10
4	The clarity of the political vision with regard to sustainability.	14	3	1,00	1,87
5	The political recognition of balancing problems.	4	9	-1,33	1,22
6	The political knowledge regarding the possibilities of storage.	26	-6	-1,00	1,26
7	The profitability of balancing via storage with respect to fossil production.	30	-8	-1,00	1,21
8	The presence of investment capital.	11	4	0,67	1,63
9	The CAPEX of storage.	32	-10	-2,00	1,21
10	The financing costs of storage.	25	-5	-1,00	1,72
11	The OPEX of storage.	28	-7	-1,00	1,60
12	The overall costs per kWh of stored electricity.	31	-10	-2,00	1,03
13	The societal attention with regard to the reliability of the network.	18	-2	0,00	0,52
14	The societal recognition of balancing problems.	16	-1	0,00	0,75
15	The societal support with regard to making the electricity sector more sustainable.	3	9	2,00	1,22
16	The societal acceptance of higher electricity prices.	24	-4	-1,00	2,07
17	The societal knowledge and trust in storage.	20	-3	-1,00	0,84
18	The social recognition of the benefits of renewable electricity.	10	4	1,00	1,37
19	The technological possibilities of storage for grid balancing.	2	9	2,00	1,05
20	The technological possibility with regard to the substitution of fossil fuels.	5	7	1,00	1,33
21	The practical and theoretical knowledge of storage in the Netherlands.	13	3	1,00	1,38
22	The presence of qualified personnel in the Netherlands.	13	3	1,00	1,38
23	The availability of raw materials for storage.	27	-7	-1,00	1,47
24	Alternatives for sustainability such as Carbon Capture and Storage.	30	-8	-1,00	1,21
25	The legal separation between production, trade and distribution of electricity.	23	-3	-1,00	1,87
26	The regulations regarding implementation of storage.	21	-3	-1,00	1,38
27	The anti-discriminatory nature of the regulations with regard to electricity production.	22	-3	-1,00	1,52
28	The policy ambiguity of the term "energy neutral".	12	3	1,00	0,84
29	The law permits the implementation of storage.	6	7	1,00	1,72
30	The schemes for subsidies for storage.	8	5	1,00	1,33
31	The integration of environmental damage into electricity prices.	10	4	1,00	1,37
32	The presence of geographical features required for storage.	15	2	0,00	0,82
33	The decentralized location of renewable electricity sources.	17	-1	0,00	1,33
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	23	-3	-1,00	1,87
35	The "level playing field" between renewable and fossil electricity production.	19	-2	0,00	1,51
36	The current availability and prices of fossil fuels.	29	-7	-1,00	1,72

Table 4A – The Sum of Scores Attributed per PESTLE Theme

	Total Score
Political	27
Economical	-36
Social	3
Technological	7
Legal	6
Environmental	-7

A notable observation is the negative scores attributed to statement 6 - *The political knowledge regarding the possibilities of storage.* The respondents expect policymakers and regulations to positively influence the uptake of innovations in the power grid, However, other expert stakeholders should provide the details and take care of its execution.
This is illustrated by respondent 1, describing who should take responsibility for outlying the long-term goals with regard to changes in the Dutch power grid:

'This is extremely suitable for policy makers and network managers. It is primarily to them to form a vision. They can set out the lines with sufficient (innovative) freedom for market parties to come up with the best standards and technologies.'

The second ranking statement is statement 19 - *The technological possibilities of storage for grid balancing.* This high score indicates confidence in current technology to mitigate balancing challenges but is however contradicted by the results of the third survey. In this survey, none of the respondents believe the current level of technology suffices for perform the system requirements. The respondents assess the solution for balancing will be of technological nature and that the required storage application will develop gradually to meet the challenges.

The aggregated score of 3 points for societal-related factors (statements 13 to 18) suggests that the society is ambivalent towards the integration of storage applications. Statement 15 however is ranking third, with an average value of 2.00. As such, sustainability might be a leading factor in society.

With regard to economical statements, five out of six statements score negative values, and include the two lowest scoring statements:

9 -The CAPEX of storage, and;
12 -The overall costs per kWh of stored electricity.

This should be considered in combination with the negative scores attributed to the statements:

35 - The level playing field between renewable and fossil electricity production, and;
36 -The current availability and prices of fossil fuels.

This raises the question whether respondents assess the actual price of storage applications to be high, or only consider the economic viability of storage applications in direct competition with current technologies based on fossil generation.

It is notable that statements 25 and 34, describing the separation of duties in the energy sector, both have a high standard deviation. This indicates some disagreement between the respondents and requires more detailed investigation in a later stage.

In general, the respondents agree that the two most influential forces are political and economic. The follow up analysis is used to provide more details, on institutional level, by looking into the distinction between perspectives within the group of respondents. Furthermore, it serves to explore whether the detailed analysis provides any insight in how the societal, technological, legal and environmental factors are considered and above all, explore the correlation between the forces themselves. The first step is to identify statistically measurable distinction in viewpoints.

General Exploration of Distinctive Viewpoints

Hitherto, the Sorts are mainly viewed by looking at individual statements. *Table 5* shows the correlation between the respondents in the execution of the Q-Sorts and is therefore a better indication of the level of conformity between respondents.

The first observation is the absence of negative correlations in both sorts, indicating overall agreements between the respondents. The second observation is the absence of clear groupings, although this can also be attributed to the low number of respondents. Only Respondents 5 and 6 are highly correlated in the first Sort. They may thus represent a common perspective. Their agreement in the second sort is however lower. Respondent 2 seems to agree with most respondents in both sorts. Respondents 3 and 4 disagree with most other respondents and are thus interesting, as they might represent the outsider's point of view.

Table 5 - Correlation Matrix between Sorts

Table A: Q - Sort 1						
respondent	1	2	3	4	5	6
1	1	0.45	0.22	0.00	0.28	0.28
2		1	0.60	0.17	0.35	0.40
3			1	0.25	0.00	0.22
4				1	0.15	0.50
5					1	0.80
6						1
Table B: Q - Sort 2						
respondent	1	2	3	4	5	6
1	1	0.43	0.18	0.19	0.42	0.28
2		1	0.34	0.13	0.53	0.36
3			1	0.14	0.14	0.01
4				1	0.19	0.13
5					1	0.43
6						1
(green)	Strong Correlation					
(orange)	Moderate Correlation					
	Weak Correlation					

The relatively high standard deviations for statements 3, 4, 7, 8 and 9 in Q – Sort 1, as shown in *Table 3*, is interesting. This might help to explain the lower correlation in the results of the Q-Sort and thus to interpret the differences in viewpoints in the next part of the analysis. The same applies for the statements 4, 8, 10, 11, 16, 25,29, 34 and 36 in Q-Sort 2.

The distinction in viewpoints is done in the next part of the analysis, followed by the development of the perspectives.

5.2 Step 2: Extracting the Factors

The general exploration described above, indicates the presence of distinctive opinions in both Q-Sorts. The next step is to decide how many perspectives to investigate. This is done using *Principal Component Analysis*.

Table 6 - Unrotated Factor and Cumulative Communalities Matrix

	Factors					
	1	2	3	4	5	6
Eigenvalues	2.639	1.278	1.067	0.601	0.308	0.105
Expl. Variance (%)	44	21	18	10	5	2
Expl. Variance (cum. %)	44	65	83	93	98	100
	Table B: Q-Sort 2					
	Factors					
	1	2	3	4	5	6
Eigenvalues	2.418	1.042	0.913	0.678	0.534	0.416
Expl. Variance (%)	40	17	15	11	9	7
Expl. Variance (cum. %)	40	58	73	84	93	100

The Kaiser-Guttman criterion is used to select the numbers of perspectives for further investigation. An additional standard is for the factors to cumulatively explain 75% of the variance.

For Q-Sort 1, both objectives are achieved by opting to rotate around three factors. For Q-Sort 2 however, the statements adhering to the Kaiser-Guttman criteria explain 58% of the variance. As such, it is decided to include the third factor, with an eigenvalue of 0.913, in the analysis. The follow-up analysis for both sorts will explore three distinctive perspectives within the group of six respondents. The subsequent step is to define which respondents represent a particular perspective. Once this is achieved, the applicable sorts can be used in consultation with the comments provided by the respondents to interpret the meaning of the perspective.

5.3 Step 3: Explore the Separation between Factors

The values shown in *Table 7* show the level of agreement of each respondent with the three, yet undefined, perspectives. In contrast to the Correlation matrix, the grouping of respondents now becomes clearer. It is remarkable that some respondents load on the same perspectives, while having a low correlation between their sorts. For example, in Q-Sort 2, the respondents 2 and 6 both on perspective 1, although the correlation between their sort is moderate.

In *Table 7,* the cells highlighted in green adhere to the criteria set by PQMethod and are selected for further analysis. The blue cell adheres to *Humphrey's rule.* This cell is rejected in order to prevent the investigation of *mixed loadings*, which are two highly intercorrelated perspectives. An additional rule-of-thumb is to reject the perspectives with less than two significant loadings. This would mean rejecting perspective 3 in Q-Sort 1, represented by respondent 4, and perspective 2 (respondent 3). In the second Q-Sort, perspective 3 (respondent 4) would be rejected. It is chosen not to do so, since these respondents are assessed to represent the perspectives of outsiders.

According to ***Fout! Verwijzingsbron niet gevonden.***, the respondents agree, or are ambivalent, to all perspectives. The exemption is respondent 1, who disagrees with perspective 3 in Q-Sort 1. A second observation is that respondent 4 seems to have a distinctive point of view compared to the other respondents in both Q – Sorts.

Table 7 - Factor Matrix Q-Sort 1 and 2

	Q-Sort 1			Q-Sort 2		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Respondent 1	0.3879	0.5888	-0.4335	0.6409	0.2333	0.1501
Respondent 2	0.2912	0.8418	0.0216	0.7147	0.4549	-0.0380
Respondent 3	-0.1318	0.8546	0.3156	0.0699	0.9219	0.0854
Respondent 4	0.2339	0.1432	0.8701	0.1195	0.0721	0.9843
Respondent 5	0.9470	0.0578	-0.0008	0.8086	0.0913	0.0889
Respondent 6	0.8620	0.2090	0.3734	0.7587	-0.2559	0.0660
% Variance	32	31	20	36	20	17
(green)	Adheres to PQMethod Criterion					
(blue)	Adheres to Humphrey's rule					

The distinction between perspectives can also be distilled out of the *Table 8,* illustrating the statistical level of agreement in-between perspectives. As a rule of thumb, correlation up to 0.1 are considered trivial, between 0.1 and 0.3 are small, between 0.3 and 0.5 moderate and correlation greater than 0.5 are considered large.

Table 8 - Correlation Matrix between Factor Scores

Table A: Q-Sort 1			
Factor	1	2	3
1	1	0.2666	0.2538
2		1	0.2232
3			1
Table B: Q-Sort 2			
Factor	1	2	3
1	1	0.2079	0.2130
2		1	0.1444
3			1

As such, the correlations between the three perspectives in both sorts are small. This is positive, as it suggests that the meaning between perspectives is distinctive.

Consensus Statements

The first step is to find the common factors between the viewpoints. This is done by defining the *consensus statements,* the statements sorted in a similar manner within the various perspectives. The notable consensus statements are shown in *Table 9.*

Table 9 - The relevant Consensus Statements

		Perspective 1		Perspective 2		Perspective 3	
#	Statements	Q-Value	Z-Score	Q-Value	Z-Score	Q-Value	Z-Score
1	The separation of the production and usage of electricity in terms of time.	3	1.91	1	1.01	2	1.22
5	To increase the efficiency of fossil production.	-3	-1.91	-2	-1.61	-3	-1.84
6	To enable handling the greater pressure on the network.	2	1.28	2	1.23	1	0.61
10	To maintain the current reliability to enable economic security.	0	0.17	0	-0.22	0	0.00
11	To maintain the current reliability to maintain the current standard of living.	0	0.00	0	0.14	0	0.00
16	PerformingEnergy Management.	0	0.00	1	0.49	0	0.00

		Q-Sort 2					
		Perspective 1		Perspective 2		Perspective 3	
#	Statements	Q-Value	Z-Score	Q-Value	Z-Score	Q-Value	Z-Score
3	The political attention with regard to making the electricity sector more sustainable.	1	0.62	1	0.62	1	0.62
5	The political recognition of balancing problems.	2	1.13	2	1.25	2	1.25
7	The profitability of balancing via storage with respect to fossil production.	-2	-0.95	-2	-1.25	-2	-1.25
12	The overall costs per kWh of stored electricity.	-2	-1.31	-2	-1.25	-2	-1.25
Non-Significant P > 0,01. Green filled cells P > 0,05.							

In Q-Sort 1, the statistical consensus aligns with the previous findings. All perspectives have in common the high scores attributed to statements 1 and 6 and for the low scores given to statement 5. The statements 10, 11 and 16 are considered ambivalent in each perspective.

For Q-Sort 2, a distinction with previous findings can be found. Although statement 3 is the highest-ranking statement in Table 4, it is statement 5, ranking fourth on aggregated scores, that all perspectives consider in common as the biggest opportunity. Statements 7 and 12 are considered the biggest barriers in all perspectives.

Although these statements are important to deduct the meaning of the individual perspectives, they do not enable to deduct the *distinction* between these meanings. The *array of differences* however does.

Array of Differences between Perspectives

In contrast to the Consensus statements, the *Array of Differences* show the difference in attributed scores to each statement in the different perspectives. These statements are interesting, as they help to explore the distinction in viewpoints.

Table 10 - Array of Differences

Array of Differences Q-Sort 1		Perspectives		
#	Statement	1 & 2	1 & 3	2 & 3
3	To enable the substitution of fossil fuels through conversion.	2,50		3,09
4	To stabilize the variable output of renewable electricity.	2,15		2,13
7	To enable the integration of energy networks, such as gas and electricity.	2,17	1,72	
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).		2,60	1,47
9	To maintain the current reliability to guarantee safety.		1,89	
Array of Differences Q-Sort 2		**Perspectives**		
#	Statement	1 & 2	1 & 3	2 & 3
8	The presence of investment capital.		2,26	2,49
10	The financing costs of storage.	2,14		3,12
11	The OPEX of storage.	2,71		2,49
21	The practical and theoretical knowledge of storage in the Netherlands.	2,25		
25	The legal separation between production, trade and distribution of electricity.		3,01	
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.		3,16	

Table 10 shows the three statements with the highest difference in attributed scores between the perspectives for both Q-Sorts.

5.4 Step 4: Interpretation of Perspectives

The final step in the analysis is to interpret the meaning of the different perspectives. In order to do so, both the quantitative data deducted from the statistical analysis and the qualitative feedback provided by the respondents is used. For each perspective, a table is included showing the *Characterizing* and *Distinctive Factors,* as well as the qualitative comments provided by the respondents.

The top half of the tables show the statements attributed positive scores by the applicable and the bottom half show the statements the respondents disagrees with. The applicable respondents are coloured in blue, while, for comparison, the respondents associated to the other perspectives are shown in black. The relevant factors shown in ***Fout! Verwijzingsbron niet gevonden.*** are used as well.

5.4.1 Q-Sort 1 – The Necessities of Implementing Storage Applications

The first Q-Sort is developed to answer Research Sub-Question 4 by investigating how respondents perceive the roles of storage applications in the Dutch Power Grid. The statistical analysis suggests the presence of three distinct perspectives.

Perspective 1: Increase Sustainability via Technology, but Safety First

Perspective 1 is defined by the respondents 5 and 6.

Narrative

The first perspective embraces the need for sustainable innovation in the energy sector, accepting the associated costs. It however emphasizes the importance of safety. This is illustrated by respondent 5, claiming that the innovations should be implemented as soon as technologically possible, but: '*should start on a small scale to enable knowledge development and improvement of technology'.* Furthermore, full electrification of the energy sector is not considered a viable solution. An alternative energy carrier is needed to replace fossil fuels. Both the emphasis on safety and the need to develop an alternative fuel arguably originates from the shared origin of shipping.

Substantiation

The first notable observation is the discrepancy in quantitative and qualitative information with regard to *statement 8: To enable the integration of the electricity sector with other sectors (for example the transport sector).* This statement is distinguishing as the other perspective value it either neutral (perspective 2) or the most important necessity (perspective 3), while perspective 1 attributes it a negative value.

Respondent 6 however states: *'The integration of the electricity sector with other sectors sounds good, but I cannot imagine how this would work.'*

As such, this statement can no longer be qualified as distinguish, as respondent 6 should actually attribute it a positive value. Considering the equivalent technological scope of statement 7, and the lack of qualitative information, arguably the same disqualification applies to this statement.

The statement does not distinct itself when looking at the *Characterizing Statements*, as both other perspective (dis)agree in a similar way. It is clear from the comments that fossil fuel should be substituted in time, and that the solution should be sought in technology rather than cultural awareness or financial incentives.

As such, the distinction is to be sought in *statement 9: To maintain the current reliability to guarantee safety*. Perspective 1 is alone in attributing this statement a positive score.

The distinction between perspective 1 and perspective 2 is its focus for the substitution of fossil fuels with another energy carrier. IN Perspective 2, the focus is on statement 3, describing the implementation of renewable electricity.

Table 11 - Statements characterizing Perspective 1 QSORT1

Agreement							
Relevant Respondents		respondent 5 and 6		respondent 1, 2 and 3		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 2		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
1	The separation of the production and usage of electricity in terms of time.	+3 (1)	1,91	+1 (4)	1,01	+2 (3)	1,22
	Relevant Quotes						
	respondent 5: This is the biggest challenge in the electricity sector that needs to be addressed. respondent 6: Production and usage will never be coordinated, so a solution must be found.						
Distinguishing statements							
9	To maintain the current reliability to guarantee safety.	+2 (3)	1,28	-1 (13)	0,45	-1 (13)	-0,61
Disagreement							
Relevant Respondents		respondent 5 and 6		respondent 1, 2 and 3		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 2		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
5	To increase the efficiency of fossil production.	-3 (16)	-1,91	-2 (15)	-1,61	-3 (16)	-1,84
	Relevant Quotes						
	respondent 5: Increasing the efficiency of fossil electricity production is a waste of effort. respondent 6: Increasing the efficiency of fossil production only distracts from the ultimate goal of sustainable energy.						
	Others quoting on statement 5						
	respondent 3: This is not relevant for energy storage.						
	Distinguishing statements						
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).	-1 (12)	-0,76	0 (7)	0,36	+3 (1)	1.84
7	To enable the integration of energy networks, such as gas and electricity.	-2 (12)	-1,11	+2 (15)	1,07	+1 (16)	0,61
	Relevant Quotes on Statement 8						
	respondent 6: The integration of the electricity sector with other sectors sounds good, but I cannot imagine how this would						
	Others quoting on statement 8						
	respondent 4: Connecting the energy sector with other sectors can lead to an acceleration of the energy transition. For example, converting food into energy, turning energy into mobility, turning food into mobility, etc.						
Significance P < 0,05. Green filled cells P < 0,01.							

Perspective 2: No-Nonsense - Prepare the Power Grid, Policy is Instrumental.

Perspective 2 is defined by the respondents 1, 2 and 3.

Narrative

Perspective 2 has three strong focus points:

Renewable production should substitute fossil-based electricity generation as soon as possible.
The implementation of storage and conversion applications is needed to enforce the power grid to enable the above.
In terms of technology and economics, a lot is already possible and economics. However clear policy is instrumental to enable the implementation.

Perspective 2 represents the no-nonsense view of taking immediate actions, but recognizes correct policy and regulations are instrumental. The execution is however best left to the market and the monitoring of the effectiveness and compliancy should not be done by politicians, but by subject matter experts. The challenges, both technological and economical, are solved on the go or during pilot projects.

It is clear fossil generated electricity is to be replaced by renewable production and, as such, storage and conversion applications are needed to create flexibility in grid and to enable the integration of the power and gas infrastructure. This solves the two emergency issues of maintaining the equality constraint due to the intermitted nature of renewable production and the lack of capacity of the power grid due to electrification.

Substantiation

The no-nonsense mentality was clear during the discussions and presentations attended during an event on energy transition and is also clear looking at the comments provided by the respondents. The answers are short and to the point. *'This is the essence of storage'* and *'This is why storage is needed'* are just two examples.
The goal is clear: to enable the grid to deal with the integration of renewable electricity production in order to end fossil generation. This is illustrated by both the positive and negative scoring characterizing statements and associated comments. The positive statements all represent necessities to enforce the grid and the score attributed to statement 4: 'To stabilize the variable output of renewable electricity', differs significantly from other perspectives. Respondent 1 quotes: *'The biggest bottleneck in the energy transition is our network.'* The elimination of fossil fuels is evident, seeing the low scores attributed to statements 3 and 5: *'We will switch completely to renewable energy and fossil will no longer be tolerated, so I do not think it is necessary to indicate substitution.'*

The recognition for policy was clear during the discussions, in which both respondent 1 and 2 presented technologically and economically feasible solutions to reduce waste of energy but argued implementation was hampered by policy and regulations. They did however admit policy is needed to enable a level playing field, set clear goals and to enable the monitoring of the progress. This recognition is also illustrated to the high scores attributed to statements describing policy and legislations, and by the substantiation comments:

> *'It is therefore primarily to the government to form a vision.'*
> *'When vision is clear, the consideration of the business case is to network operators and market parties.'*
> *'Policy is very important. The government, large companies (production and distribution) and banks must work together.'*
> *'Governments should allow the market to choose the best technologies and standards. Independent parties specialised in certification of safety and living environment can play a role in the standardization and monitoring of processes and techniques and provide quality marks.'*

Table 12 - Statements characterizing Perspective 2 QSORT1

Statements characterizing Perspective 2							
Agreement							
Relevant Respondents		respondent 1, 2 and 3		respondent 5 and 6		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
4	To stabilize the variable output of renewable electricity.	+3 (1)	1,51	-1 (11)	-0,64	-1 (13)	-0,61
	Relevant Quotes						
	respondent 3: This is why energy storage is needed.						
	Quotes on other Statements with +3 score						
6	To enable handling the greater pressure on the network.		respondent 1: The biggest bottleneck of the energy transition is our network. In the light of our climate agreement, we must therefore focus on the energy				
1	The separation of the production and usage of electricity in		respondent 2: This is the essence of storage.				
Distinguishing statements							
4	To stabilize the variable output of renewable electricity.	+3 (1)	1,51	-1 (11)	-0,64	-1 (13)	-0,61
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).	0 (7)	0,36	-1 (12)	-0,76	+3 (1)	1.84
Disagreement							
Relevant Respondents		respondent 1, 2 and 3		respondent 5 and 6		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
3	To enable the substitution of fossil fuels through conversion.	-3 (16)	-1,86	+1 (4)	0,64	+2 (3)	1,22
	Relevant Quotes						
	respondent 1: In the end we will switch completely to renewable energy and fossil will no longer be tolerated, so I do not think this is necessary to indicate substitution. It will happen automatically.						
	Quotes on other Statements with -3 score						
5	To increase the efficiency of fossil production.		This is not relevant for energy storage.				
	Distinguishing statements						
3	To enable the substitution of fossil fuels through conversion.	-3 (16)	-1,86	+1 (4)	0,64	+2 (3)	1,22
Significance P < 0,05. Green filled cells P < 0,01.							

Perspective 3: Sustainable Development and Equity by Maximizing Flexible Usage of Energy

Perspective 3 is defined by respondent 4.

He has a very distinctive opinion in both Sorts, grossing only weak correlations with the other individual respondents, as shown in *Table 5 - Correlation Matrix between Sorts.* As such, he represents an outlier perspective.

Narrative

The priority for perspective 3 is to create fairness in the energy sector by minimizing the negative externalities of energy production and distributing the remaining goods within the society, notwithstanding of cost and benefits. Therefore, fossil fuels should be substituted as soon as possible within all energy sectors. The main goal of storage applications is to enable flexible flow to, and usage of, energy by anyone.

Substantiation

Respondent 4 gave a presentation and hosted a non-structured discussion on the importance of trust in society with regard to the energy sector in order to make the energy transition a success. In the current market environment, only few benefit from the trade of energy. The costs and associated damage however, have consequences for everyone. Energy should not be considered as a marketable product, but as a valuable resource for society. The distribution of energy should be based on fairness and not equality in order to reach the same level of good within society. The same applies to other resources such as food and water.

The most important observation is that energy should not be subject to any form of market forces. This is mainly reflected in the qualitative information provided by the respondent. A selection of comments provided in the survey:

> *'The complete energy system should be owned by a single entity and become a fully public responsibility.'*
> *'Reducing fossil should be priority number one for the climate. Making it's usage more efficient is only tolerating delay.'*
> *'The strict separation of duties ensures a system in which interests must always compete with each other. This should be prevented.'*
> *'Focus on money causes unwanted delays.'*
> *'Storage in the energy sector can be used immediately, but only if it is kept completely out of the speculation and commerce of market forces.'*

As such, perspective 3 does not solely focus on the power grid. The perspective introduces storage applications as a mean to enable a holistic distribution of electricity in all energy related sectors, as well as a mean to enable the integration with other sectors such as food. This is illustrated by the high score for statement 8 and the associated feedback:

'Connecting the energy sector with other sectors can lead to an acceleration of the energy transition. For example, converting food into energy, turning energy into mobility, turning food into mobility, etc.'

Table 13 - Statements characterizing Perspective 3 QSORT1

Agreement							
Relevant Respondents		respondent 4		respondent 5 and 6		respondent 1, 2 and 3	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 2	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).	+3 (1)	1.84	-1 (12)	-0,76	-3 (16)	-1,86
	Relevant Quotes						
	respondent 4: Connecting the energy sector with other sectors can lead to an acceleration of the energy transition. For example, converting food into energy, turning energy into mobility, turning food into mobility, etc.						
	Others quoting on statement 8						
	respondent 6: The integration of the electricity sector with other sectors sounds good, but I cannot imagine how this would						
Distinguishing statements							
8	To enable the integration of the electricity sector with other sectors (for example the transport sector).	+3 (1)	1.84	-1 (12)	-0,76	-3 (16)	-1,86
Disagreement							
Relevant Respondents		respondent 4		respondent 5 and 6		respondent 1, 2 and 3	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 2	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
5	To increase the efficiency of fossil production.	-3 (16)	-1,84	-3 (16)	-1,91	-2 (15)	-1,61
	Relevant Quotes						
	Reducing fossil should be priority number 1 for the climate. Making it's usage more efficient is only tolerating delay.						
	Others quoting on statement 5						
	respondent 5: Increasing the efficiency of fossil electricity production is a waste of effort.						
Distinguishing statements							
14	Performing Power Quality Management.	-2 (15)	-1,22	+1 (6)	0,47	0 (9)	0,00
Significance P < 0,05. Green filled cells P < 0,01.							

Conclusion Q-Sort 1

The results of Q-Sort 1 answer the research sub-question 4, which is:

How do the various respondents perceive the roles of storage applications on the Dutch power grid?

Respondents perceive the implementation of storage applications as a technological requirement to ensure the functioning of the power grid. Their confidence to deal with the anticipated challenges through the promotion of behavioural change is low. This is illustrated by respondent 1: '*The production and usage of electricity will never be coordinated, as such a technological solution must be found.'* Although the societal recognition for sustainable development is high, the societal awareness for the role of the power grid is low. Moreover, the respondents doubt whether the society is willing to incur higher costs. As such, the implementation of storage applications should not be left to the individual consumer but should be executed by utilities.

The respondents perceive the main benefit is to enable the separation in time between the generation and usage of electricity. Respondent 2 states: *'This is the essence of storage.'* The focus is again on the provision of a technological solution for the challenges with regard to the equality constraint.

Three separate perspectives emerge from the analysis of the survey. Although they all have in common that they recognize the need to facilitate the further integration of renewable electricity production, there are nuances. The integration of renewable electricity is actively pursued by the respondents associated to perspective 2. The implementation of storage applications is a mean to achieve this objective. In the other two perspectives, the integration of renewable electricity is considered a societal development, albeit one that needs to be accommodated. A second agreement is that the role of storage applications in order to increase the effectivity of fossil-based energy production is rejected in the narrative of all perspectives.

The respondents recognize that the implementation of storage applications can enable phasing out the usage of fossil energy. They emphasize the importance of increasing the ration of renewable electricity generation in the energy mix. The substitution of fossil-based fuels with a renewable *energy carrier* through the conversion of electricity is however not seriously considered. Subsequently, the attention attributed to the opportunities of storage applications to integrate multiple energy related infrastructures and sectors is low. As such, the respondents perceive the major role of storage applications is to provide tools to enable load levelling and power quality management on the power grid.

Answering the research sub-question:
The implementation of storage and conversion applications is a <u>technological requirement</u> at <u>utility level.</u> Their main roles are to:

Perspective 1: Guarantee safety during the energy transition.
Perspective 2: Enable the integration of renewable electricity generation.
Perspective 3: Enable an equitable distribution of good in a sustainable future.

5.4.2 Q-Sort 2 - Opportunities and Barriers for the Implementation of Storage

Q-Sort 2 looks into Research Sub-Question 5 and 6. The statements in the Q - Set were equally divided between the external forces associated to the PESTLE analysis.

Opportunities and Barriers on a General Level

The bottom of *Table 14* shows the scores attributed to the 36 statements which are part of the Q – Set. In the top of *Table 14,* the scores are summed per external factors. It thus shows the aggregated scores attributed to statements related to policy, economy, and so on. This is done for the average scores of the sorts provided by all respondents and for the average scores for each perspective.

Table 14 - QSORT2 General Overview of Barriers and Opportunities

		Overall	Perspective 1	Perspective 2	Perspective 3
		Sum of Z-Scores	Sum of Z-Scores	Sum of Z-Scores	Sum of Z-Scores
	Political	9,67	2,82	3,73	3,12
	Economical	-13,21	-4,47	0	-8,74
	Social	-1,65	2,7	-4,35	0
	Technological	-1,45	2,91	-3,12	-1,24
	Legal	7,99	-1,99	4,99	4,99
	Environmental	-1,35	-1,97	-1,25	1,87
#	Statement	Z-Scores	Z-Scores	Z-Scores	Z-Scores
1	The political attention with regard to the reliability of the network.	1,11	0,49	0,62	0,00
2	The political long-term vision of the network.	1,77	0,53	0,62	0,62
3	The political attention with regard to making the electricity sector more sustainable.	3,13	1,89	0,62	0,62
4	The clarity of the political vision with regard to sustainability.	1,58	-0,29	0,62	1,25
5	The political recognition of balancing problems.	3,63	1,13	1,25	1,25
6	The political knowledge regarding the possibilities of storage.	-1,55	-0,93	0,00	-0,62
7	The profitability of balancing via storage with respect to fossil production.	-3,45	-0,95	-1,25	-1,25
8	The presence of investment capital.	1,01	1,01	1,25	-1,25
9	The CAPEX of storage.	-3,99	-0,87	-1,25	-1,87
10	The financing costs of storage.	-1,51	-0,89	1,25	-1,87
11	The OPEX of storage.	-1,46	-1,46	1,25	-1,25
12	The overall costs per kWh of stored electricity.	-3,81	-1,31	-1,25	-1,25
13	The societal attention with regard to the reliability of the network.	-0,75	-0,13	-0,62	0,00
14	The societal recognition of balancing problems.	-0,55	0,07	-0,62	0,00
15	The societal support with regard to making the electricity sector more sustainable.	2,46	1,84	0,00	0,62
16	The societal acceptance of higher electricity prices.	-2,30	0,19	-1,87	-0,62
17	The societal knowledge and trust in storage.	-1,57	-0,33	-0,62	-0,62
18	The social recognition of the benefits of renewable electricity.	1,06	1,06	-0,62	0,62
19	The technological possibilities of storage for grid balancing.	2,18	1,56	0,62	0,00
20	The technological possibility with regard to the substitution of fossil fuels.	1,38	1,38	0,00	0,00
21	The practical and theoretical knowledge of storage in the Netherlands.	-0,25	1,00	-1,25	0,00
22	The presence of qualified personnel in the Netherlands.	-0,09	1,15	-0,62	-0,62
23	The availability of raw materials for storage.	-2,63	-0,76	-1,87	0,00
24	Alternatives for sustainability such as Carbon Capture and Storage.	-2,04	-1,42	0,00	-0,62
25	The legal separation between production, trade and distribution of electricity.	0,74	-1,13	0,00	1,87
26	The regulations regarding implementation of storage.	-0,24	-0,87	1,25	-0,62
27	The anti-discriminatory nature of the regulations with regard to electricity production.	0,36	-0,89	0,00	1,25
28	The policy ambiguity of the term "energy neutral".	1,43	0,18	0,00	1,25
29	The law permits the implementation of storage.	2,96	0,47	1,87	0,62
30	The schemes for subsidies for storage.	2,74	0,25	1,87	0,62
31	The integration of environmental damage into electricity prices.	0,95	0,95	0,62	-0,62
32	The presence of geographical features required for storage.	0,89	0,27	0,62	0,00
33	The decentralized location of renewable electricity sources.	-0,82	-0,19	-1,25	0,62
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	0,58	-1,29	0,00	1,87
35	The "level playing field" between renewable and fossil electricity production.	0,07	-0,56	-0,62	1,25
36	The current availability and prices of fossil fuels.	-3,02	-1,15	-0,62	-1,25

In general, *Table* 14 aligns with *Table 4A*. Policy is considered the most important driver for the implementation of storage applications (sum of Z-Scores +9,67). The biggest barrier is the influence of economic factors (-13,21). The influences of societal, technological and environmental factors are perceived as marginal. In *Table 14,* the role of regulatory factors was perceived as a driving force (+7,99). This differs from the findings in *Table 4A*.

In contrast to *Table 4A, Table 14* also shows the results of the different perspectives. This enables a more detailed analysis of the results and the creation of the narratives describing the perspectives.

Unfortunately, the respondents have assessed a number of statements from different frame of references. This becomes clear when the quantitative and qualitative data attributed to these statements are compared.

The feedback on policy, given by the respondents, is mainly negative:

> *Respondent 5*, on *statement 4*: *'The political vision is completely missing.'*
> *Respondent 3*, on *statement 16*: *'Politicians are not always willing to upset voters.'*
> *Respondent 4,* on *statement 25*: *'Policymakers should realize that an energy system is vital for society and should be brought fully into public ownership within a single or limited number of companies spanning the full chain.'*

The sum of the scores attributed to the statements describing the role of policies are however positive. There is currently a lot of attention for environmental development. It seems that the respondents assessed the statements within this frame of reference. As such, the attribution of high scores might have been done based on *anticipated future policies*. The goal of the Q-Sort however was to value the *current* policies.

The same does not apply to the statements describing economic factors. In Chapter 2 and 3, it is deducted that the costs of *hybrid systems* are expected to approach the costs of fossil-based flexibility. As such, various researches predict *hybrid systems* to become economically competitive in the future. The respondents did not value the economic statements from the frame of reference of this *anticipated future*:

> *Respondent 4* on *statement 9*: *'Costs are still high. It is almost impossible without subsidies.'*
> *Respondent 5 statement 11*: *'Conversion of electricity to make storage possible is inefficient and therefore expensive.'*

As such, the scores attributed to the various statements are biased. The quantitative results of the survey should thus be analysed in relation with the qualitative feedback provided by the respondents.

Political Factors

As previously discussed, the (anticipated) role of policy is considered to be the *leading driving force* for the implementation of storage applications. The role of policies is however limited to the initiation of change and not its execution. The political recognition for the need of environmental development (Statements 3 and 4) and safety and security (Statements 1 and 5) are considered to be opportunities. On the other hand, the respondents value the actual knowledge of politicians with regard to storage applications as a barrier (statement 6). Therefore, the respondents require policy makers to develop and communicate clear goals, but to subsequently enable subject experts to choose the best processes and technologies to achieve these goals.

Economic Factors

The current economic and market forces are considered the biggest barriers for the implementation of storage applications. This negative view is primarily due to the high investment costs of storage (*statement 9*). The financing cost are the secondary barrier (*statement 10*) and finally, the operational costs (*statement 11*). This reduces the competitive position of hybrid systems compared to the flexibility provided by fossil fuels (*statement 7*). This is in line with the scores attributed to *statemen*t 36. The presence of investment capital is assumed to be an opportunity (*statement 8*). This positive assessment is interesting. It raises the question whether the respondents are assessing the current presence of investment capital in the market or expect future policies to deliver this.
Perspective 2 attributed neutral scores to the economic statements. This suggests a different viewpoint and will be investigated in more detail in the further analysis.

Societal Factors

There is a big difference between the three perspectives in the attribution of scores to statements describing the influence of society. In general, the societal attention for sustainable development is considered an opportunity (*Statement 15 and 18*). However, the respondents do not assess society to correctly value the benefits of storage (statement 17). Society's awareness for the challenges on the grid is low (statement 13 and 14). Furthermore, the respondents do not expect consumers to accept higher individual costs (statement 16). It raises the question whether long-term environmental policies can be pursued when the costs are too high or when the benefits are not tangible. The societal factors are thus moderating factors. They are considered as opportunities with regard to environmental change, but as barriers due to the associated costs.

Technological Factors

The technological benefits of hybrid systems are not yet at a level to enable technology-driven change in the sector. Their development is influenced by the other external forces. Therefore, the question is how the respondents perceive the current maturity of storage applications with regard to their capability to perform the required system services. The scores attributed to the *statements 19* and 20 are positive, suggesting that the respondents are positive about the current capabilities.

In the fourth survey however, the respondents are asked when the implementation of storage applications should start. Two respond this should start as soon as it is technologically feasible. Another two think this will happen as soon as these technologies are lucrative. One states the implementation should start immediately and that the required innovations will develop on the go. Finally, the last respondent states that the energy sector should first be removed from the market environment and should become a societal system before other investments are made. None of the respondents chose the option stating that it is already technologically feasible. This raises the question whether the scores attributed to *statements 19* and *20* are based on the current technology or that the respondents are positive about the development of future technology.

The availability of materials is a salient factor (*statement 23*) while the practical and theoretical knowhow is an issue to keep an eye on (*statement 21 and 22*). The influence of competitive technologies to enable sustainable flexibility is unclear (*statement 24*). The attributed scores suggest this to be a barrier. In the feedback however, respondents are sceptical of alternatives such as *CCS*. As *respondent 4* states *'There are no real alternatives to storage, or it must be H2 storage. But certainly not CCS.'* As such, it can be argued that the negative value attributed to *statement 24* should be disregarded. This would lead to a slightly positive view on technological factors.

Legal Factors

The respondents perceive the current regulatory framework as an opportunity for the implementation of storage. This raises the question whether the respondents consider these factors as an extension of policy. Furthermore, it is again not clear whether they value *current* or *anticipated regulations.* The regulatory separation of the roles and responsibilities on the power grid, as depicted by *statement 25* for example, is considered a barrier by the respondents associated to the first perspective. In the third perspective however, it is considered an opportunity. The feedback on this statement is not clear:

Respondent 6 - perspective 1: *'Policymakers are forced to take action.'*
Respondent 4 - perspective 3: *'The strict separation of duties ensures a system in which interests must always compete with each other.'*

Two observations are made. First, the view on the regulatory factors is coupled to political factors in perspective 1. This substantiates the claim that legal aspects are considered as an extension of policy. Furthermore, it suggests that the statement is assessed from the point of view of anticipated changes in legislation due to shifts in policy.

The second observation is that the respondent representing perspective 3 also attributed high scores to *statement 34*. However, the same respondent quoted: *'An energy company should be owned by a single company, without the division in commercial and public roles.'* As such, it was expected statements 25 and 34 would represent barriers. This calls for a practical approach when assessing the statistical results of perspective 3.

Perspective 1: The Window of Opportunity is Open for Sustainable Development

Perspective 1 is defined by respondents 1, 2, 5 and 6.

Narrative

To quote *respondent 5*: *'Society wants to become more sustainable, so the time is ripe to make the electricity sector more sustainable.'* The need for environmental protection is a major issue in the current spirit of time. This is an opportunity, as the implementation of storage applications is often considered complementary to the integration of renewable electricity generation. It is already technologically feasible, despite that technology is not yet mature. There is enough knowledge to make it happen. In the current market environment, *hybrid* systems cannot successfully compete with fossil-based electricity generation. As such, change should be actively sought after by developing a clear regulatory framework in favour of alternative generation methods. The current policies are a salient factor. However, the awareness of policy makers is high, which can lead to positive developments in legislation.

There should be a clear division of roles. The role of policy is to actively promote the phasing out of fossil fuels and to simultaneously act as launching customer for alternative forms of energy. Therefore, policy makers should express clear and unambiguous goals. The actual implementation should be done by subject matter experts and executed within the market environment.

Substantiation

According to *Table 4,* the view illustrated by this perspective differs from perspectives 2 and 3 by considering the societal and technological factors as opportunities and the current regulations as barriers. The respondents are thus positive about the capabilities to implement sustainable change. This is reflected by the scores attributed to the *characterizing* and *distinguishing statements* 3, 15 and 20. These statements all emphasize sustainability. Furthermore, the comment provided to statement 5 reads: *'Policymakers recognize that balancing is essential for <u>sustainability</u>'.* The societal support is deducted from *statement* 15 and its feedback: '*Society wants to become more sustainable.'* Furthermore, the score attributed to *statement 16* is, although low, positive.

The trust in technology is derived from the high scores attributed to the *characterizing* statements 19 and 24, as well as the associated feedback:

On statement 19 -	*'Battery storage and affiliated balancing technologies are well developed. It is thus technologically feasible'*
On statement 24 -	*'There are no real alternatives to storage, or it must be H2 storage. But certainly not CCS',*

The technology is not considered to be economically competitive in current market environment. This is illustrated by the *characterizing* statements 9, 11 and 12 and the *differencing* statement 10. *'Conversion of electricity to make storage possible is currently inefficient and therefore expensive'*.
The respondents however trust in the available knowledge, as reflected by the *distinguishing* statements 21 and 22.

The results are very clear on the current and expected role of policy makers. Policy is instrumental to enable the substitution of fossil-based generation, but: *'The political vision is completely missing.'* In the first questionnaire, the respondents state that policy must be state clear objectives and requirements. Government should act as launching customer, but leave the actual implementation and exploitation to subject experts and in the market environment:

'In addition, the network manager must have the option to integrate storage and to invest in storage himself or let other market parties do so'

'The vision, goal and requirements must lie with parties who really understand the subject matter. Policymakers are not necessarily suitable for determining a (technical) vision. The network operators (DSO) will have to do this in combination with market parties.

Table 15 - Statements characterizing Perspective 1 QSORT2

		Agreement					
Relevant Respondents		respondent 1, 2, 5 and 6		respondent 3		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 2		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
3	The political attention with regard to making the electricity sector more sustainable.	+3 (1)	1,89	+1 (14)	0,62	+1 (14)	0,62
15	The societal support with regard to making the electricity sector more sustainable.	+3 (2)	1,84	0 (22)	0,00	+1 (14)	0,62
	Relevant Quotes on Statement 3						
	respondent 1: Policimakers committed to the climate agreement. There is thus a lot of attentionand therefore a lot of support. respondent 2: No Comments respondent 6: Policymakers are forced to take action.						
	Relevant Quotes on Statement 15						
	respondent 5: Society wants to become more sustainable. respondent 6: The time is ripe for it.						
	Quotes on other Statements with +3 score						
5	The political recognition of balancing problems.	respondent 5: Policymakiers recognize that balancing is essential for sustainability.					
19	The technological possibilities of storage for grid balancing.	respondent 1: Battery storage and affiliated balancing technologies are well developed. It is thus technologically					
	Distinguishing statements						
3	The political attention with regard to making the electricity sector more sustainable.	+3 (1)	1,89	1	0,62	1	0,62
15	The societal support with regard to making the electricity sector more sustainable.	+3 (2)	1,84	0	0,00	1	0,62
20	The technological possibility with regard to the substitution of fossil fuels.	+2 (4)	1,38	0 (22)	0,00	0 (22)	0,00
22	The presence of qualified personnel in the Netherlands.	+2 (5)	1,15	-1 (29)	-0,62	-1 (29)	-0,62
21	The practical and theoretical knowledge of storage in the Netherlands.	+1 (9)	1	-2 (34)	-1,25	0 (22)	0,00
		Disagreement					
Relevant Respondents		respondent 1, 2, 5 and 6		respondent 3		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 2		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
24	Alternatives for sustainability such as Carbon Capture and Storage.	-3 (35)	-1,42	0 (22)	0	-1,00 (29)	-0,62
11	The OPEX of storage.	-3 (36)	-1,46	+2 (7)	1,25	-2 (34)	-1,25
	Relevant Quotes on Statement 24						
	respondent 1: There are no real alternatives to storage, or it must be H2 storage. But certainly not CCS.						
	Relevant Quotes on Statement 11						
	-						
	Quotes on other Statements with -3 score						
4	The clarity of the political vision with regard to sustainability.	Respondent 5 - The political vision is completely missing.					
6	The political knowledge regarding the possibilities of storage.	respondent 6 - I do not believe in the political expertise with regard to storage.					
9	The CAPEX of storage.	respondent 1: Costs are still high. It is almost impossible without subsidies.					
12	The overall costs per kWh of stored electricity.	respondent 5: Conversion of electricity to make storage possible is inefficient and therefore expensive.					
	Distinguishing statements						
25	The legal separation between production, trade and distribution of electricity.	-2(31)	-1,13	0 (22)	0	+3(2)	1,87
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	-2 (33)	-1,29	0 (22)	0	+3 (2)	1,87
		Significance P < 0,05. Green filled cells P < 0,01.					

Perspective 2: The Technology Trajectory is Defined by the Consumer

Perspective 2 is defined by respondents 3.

Narrative

Perspective 2 represents the market point of view. External forces are not and should not actively promote or oppose the implementation of storage. It will simply happen when society, represented by the individual consumer, requests it. Society does not perceive the technology as a marketable product, nor does it perceive an immediate need that justifies the of use public funds for its implementation. Policy makers should enable the further development of the technology through the use of subsidy.

Substantiation

The strong focus on the consumer is substantiated by comments provided during the discussion during the development of the Q - Set. When asked who should decide whether to implement storage and later who should execute the implementation, the respondents answer to both questions was: *'The consumer'.*

The positive values attributed to political and regulatory statements suggest that the potential of storage is recognized by policymakers. However: *'Politicians are not always willing to upset voters.'* The scores attributed to the statements 13 to 18 shows that respondent 3 assesses sustainability is not a major issue in society and that the awareness for its development is low. Society is led by prices and will thus not accept changes.

As such, the main barrier is society. It does not perceive a problem justifying the extra costs associated with the implementation of storage. In lieu of this, it becomes a market decision, and *hybrid systems* cannot compete with flexible fossil generation (*statement 7*). The main economic barriers are the high investment costs (statement 9) and the lack of raw materials (statement 23).

Table 16 - Statements characterizing Perspective 2 QSORT2

Agreement							
Relevant Respondents		respondent 3		respondent 1, 2, 5 and 6		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
29	The law permits the implementation of storage.	+2 (1)	1,87	+1 (13)	0,47	+1 (14)	0,62
30	The schemes for subsidies for storage.	+2 (1)	1,87	0 (15)	0,25	+1 (14)	0,62
	Relevant Quotes on Statement 29						
	respondent 3: Is storage possible if it is forbidden?						
	Relevant Quotes on Statement 30						
	respondent 3: The right arrangements reduces the risk of investing in storage.						
	Distinguishing statements						
10	The financing costs of storage.	+2 (7)	1,25	-1 (26)	-0,87	-3 (36)	-1,87
11	The OPEX of storage.	+2 (7)	1,25	-1 (28)	-0,89	-2 (34)	-1,25
25	The legal separation between production, trade and distribution of electricity.	0 (22)	0	-2 (31)	-1,13	+3 (2)	1,87
26	The regulations regarding implementation of storage.	+2 (7)	1,25	-1 (25)	-0,87	-1 (29)	-0,62
29	The law permits the implementation of storage.	+3 (2)	1,87	+1 (13)	0,47	+1 (14)	0,62
30	The schemes for subsidies for storage.	+3 (2)	1,87	0 (15)	0,25	+1 (14)	0,62
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	0 (22)	0	-2 (33)	-1,29	+3 (2)	1,87
Disagreement							
Relevant Respondents		respondent 3		respondent 1, 2, 5 and 6		respondent 4	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 3	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
16	The societal acceptance of higher electricity prices.	-3 (36)	-1,87	0 (16)	0,19	-1 (29)	-0,62
23	The availability of raw materials for storage.	-3 (36)	-1,87	-1 (24)	-0,76	0 (22)	0
	Relevant Quotes						
16	Politicians are not always willing to upset voters.						
23	Without enough raw materials, or when they are too expensive, storage becomes too expensive.						
	Distinguishing statements						
16	The societal acceptance of higher electricity prices.	-3 (36)	-1,87	0 (16)	0,19	-1 (29)	-0,62
18	The social recognition of the benefits of renewable electricity.	-1 (21)	-0,62	+2 (7)	1,06	+1 (14)	0,62
21	The practical and theoretical knowledge of storage in the Netherlands.	-2 (34)	-1,25	+1 (9)	1,00	0 (22)	0,00
23	The availability of raw materials for storage.	-3 (36)	-1,87	-1 (24)	-0,76	0 (22)	0,00
33	The decentralized location of renewable electricity sources.	-2 (34)	-1,25	0 (20)	-0,19	+1 (14)	0,62
Significance P < 0,05. Green filled cells P < 0,01.							

Perspective 3: Withdraw Utilities from the Market Environment

Perspective 3 is defined by respondent 4. He has very distinctive opinions in both Sorts, grossing only weak correlations with the other individual respondents. As such, he represents an outsider's perspective.

As previously described, the attribution of scores to the multiple statements is not in line with the qualitative feedback. This leads to doubts about the results of the survey. As the result of both Q – Sorts are based solely on respondent 4, the results of Q-Sort 1 can be used to supplement results of Q-Sort 2.

Narrative

The presence of market forces in the energy sector prevents the correct implementation of storage applications. The role of storage applications is to increase equity in society. The energy sector should be owned and operated by a public entity in which there is no room for speculation and commerce.

Substantiation

In the first Sort, the respondent states the role of storage is to increase the level of common good and of equity within society He condemns market forces for opposing this. These forces hamper the integration of clean and sustainable energy, due to their focus on profit. This is in line with his presentation during the energy transition event and discussion afterwards.

As such, the allocation of a positive score to the existence of '*a level playing field'* between fossil and renewable generation is not in line with his previous comments. The same applies to the attribution of positive scores to the statements 25 and 34. This is not coherent with the feedback: *'The energy system should be owned by a single company. This should not be subdivided into commercial and non-commercial roles and should become a public responsibility.'*

The respondents negative view on market forces is also clear when asked when he thinks storage systems should be implemented: *'Only if storage does not lead to speculation and commerce can storage be used immediately. It must be kept completely out of market forces'* and *'Focus on money causes unwanted delays.'*

Table 17 - Statements characterizing Perspective 3 QSORT2

Agreement							
Relevant Respondents		respondent 4		respondent 1, 2, 5 and 6		respondent 3	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 2	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
25	The legal separation between production, trade and distribution of electricity.	+3 (2)	1,87	-2 (31)	-1,13	0 (22)	0,00
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	+3 (2)	1,87	-2 (33)	-1,29	0 (22)	0,00
	Relevant Quotes on Statement 25						
	respondent 4: The strict separation of duties ensures a system in which interests must always compete with each other.						
	Relevant Quotes on Statement 34						
	respondent 4: Policiymakers should realize that an energy system is vital for a society and should be brought fully into public ownership.						
Distinguishing statements							
21	The practical and theoretical knowledge of storage in the Netherlands.	0 (22)	0	+1 (9)	1,00	-2 (34)	-1,25
25	The legal separation between production, trade and distribution of electricity.	+3 (2)	1,87	-2 (31)	-1,13	0 (22)	0,00
27	The anti-discriminatory nature of the regulations with regard to electricity production.	+2 (7)	1,25	-1 (27)	-0,89	0 (22)	0,00
28	The policy ambiguity of the term "energy neutral".	+2 (7)	1,25	0 (17)	0,18	0 (22)	0,00
34	The separation between public, semi-public and commercial responsibilities in the electricity sector.	+3 (2)	1,87	-2 (33)	-1,29	0 (22)	0,00
35	The "level playing field" between renewable and fossil electricity production.	+2 (7)	1,25	-1 (23)	0,56	-1 (29)	-0,62
Disagreement							
Relevant Respondents		respondent 4		respondent 1, 2, 5 and 6		respondent 3	
#	Statement	Score (Rank)	Z - Score	Perspective 1		Perspective 2	
				Score (Rank)	Z - Score	Score (Rank)	Z - Score
9	The CAPEX of storage.	-3 (36)	;-1,87	-1 (26)	-0,87	+2 (34)	-1,25
10	The financing costs of storage.	-3 (36)	-1,87	-1 (26)	-0,87	+2 (7)	1,25
	Relevant Quotes on Statement 9						
	respondent 4: Focus on money causes unwanted delays.						
	Relevant Quotes on Statement 10						
	respondent 4: 'Focus on money causes unwanted delays.						
Distinguishing statements							
8	The presence of investment capital.	-2 (34)	-1,25	+1 (8)	1,01	-2 (7)	1,25
31	The integration of environmental damage into electricity prices.	-1 (29)	-0,62	+1 (10)	0,95	+1 (14)	0,62
Significance P < 0,05. Green filled cells P < 0,01.							

Conclusion Q-Sort 2

Q-Sort 2 answers the research sub-questions 5 and 6, which are:

With regard to the implementation of electrical storage for balancing purposes in the Dutch power grid, how do the various actors perceive:

RSQ 5) *their capacity to fulfil these roles;*
RSQ 6) *the influence of the institutional factors?*

The perceived capabilities of storage applications and the influence of the external forces is discussed extensively in the analysis. In short, the respondents agree that storage applications are not economically viable in direct competition with the flexibility provided by fossil generation. The marginal costs are too high. The main barrier is due to the high initial investments. Furthermore, the technology is not developed enough to perform the required system services. The level of maturity perceived by the respondents does however differ. Perspective 1 represents great confidence in the capabilities of storage. The two other perspectives show ambivalence. The consensus between the perspectives is that policy should be the main force to actively steer the trajectory of storage. However, it needs societal support in order to succeed. Again, the level of societal support is perceived differently by the respondents representing the different perspectives. In perspective 1, the time is right to implement sustainable change. Perspective 2 is contradictory to perspective 1, assessing society sees no need to allocate resources in favour of storage. Perspective 3 states that the implementation of storage is not beneficial as long as the energy sector is influenced by market forces.

Answering the research sub-questions:
The implementation of storage applications has the technological potential to, in time, substitute fossil-based electricity generation through the integration of renewable generation. The forces influencing its trajectory are:

> *Perspective 1: The spirit of time is an opportunity for sustainable change. Storage applications are however not economically viable. Regulations are thus needed to mitigate with market forces. This will be supported by society as long as the government acts as launching customer to mitigate the associated costs.*
>
> *Perspective 2: The necessity of storage as perceived by the consumer. Currently, he perceives no need for it, that justifies the associated increase in personal costs compared to the opportunities offered by fossil energy.*
>
> *Perspective 3: The current market is driven by profit-margins. This opposes the implementation of all changes that could lead to equity.*

6. Conclusion, Discussion and Propositions

This final chapter couples the development of the Dutch electricity sector, as described in chapter 2, with the findings deducted from academic literature on storage applications and market development in general, as delineated in chapter 3. This is compared with the results of the Q-Methodological research, described in chapter 5. This research illustrates the perspectives of respondents with regard to this topic. This results in the delineation of various propositions describing the influence of the external forces on the implementation of storage applications. First, this is illustrated in more detail in a conceptual model.

6.1 The Main Research Question and Conceptual Modal

The main Research Question of this thesis is:

Why is electrical storage not widely implemented in the Dutch electrical infrastructure?

The introductory chapter deducts how the answer to this question must be sought in the detailed level of perception of the stakeholders, with regard to the various institutional factors. The results are shown in *Figure 12*.

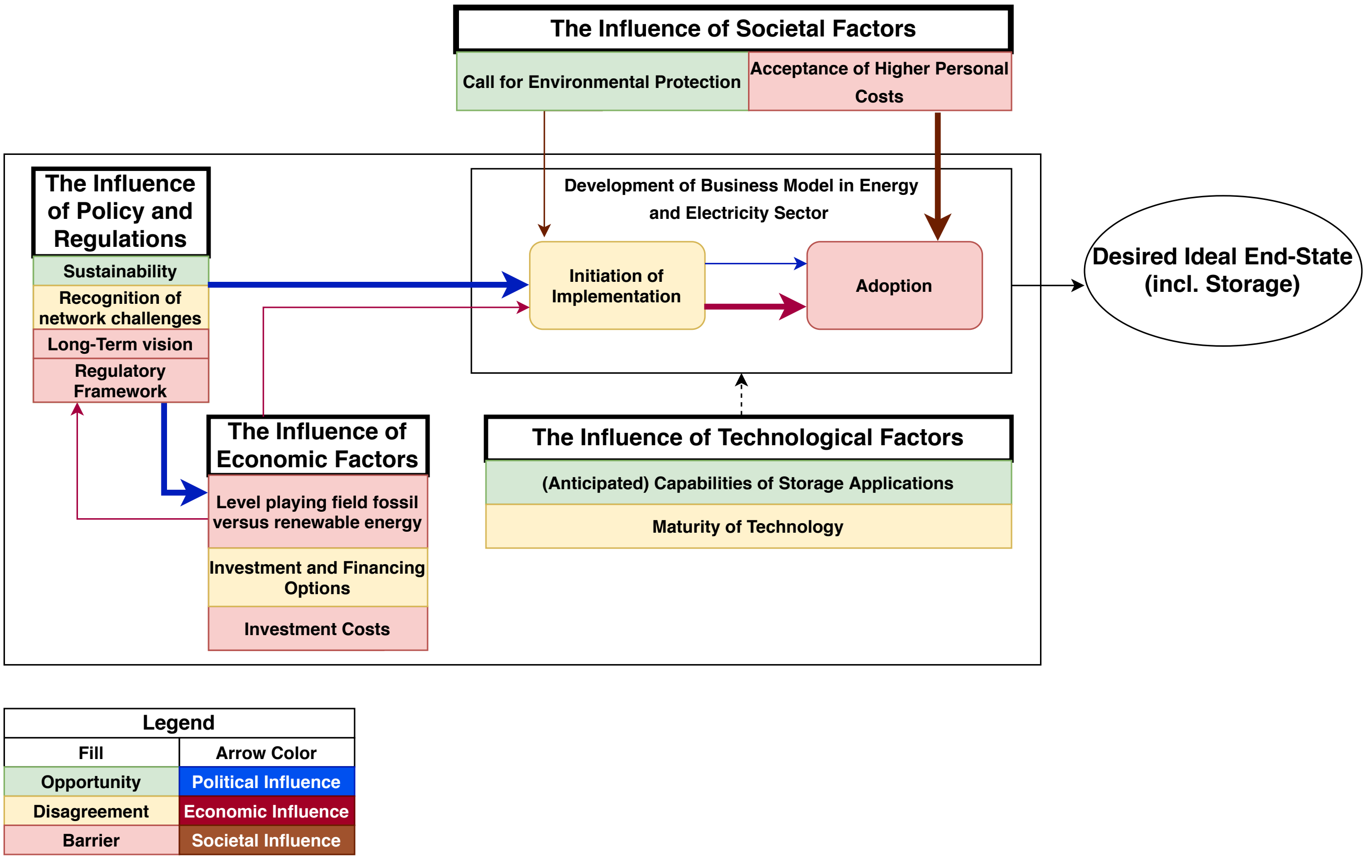


Figure 12 - Conceptual model Illustrating the Influence of the External Forces

The thickness of the arrows illustrates the size of the influence of the various external forces on the development of the *ideal end-state*. The report discusses why this development requires considerable changes in the way we look at the electricity sector and its operations.

Policy and regulations are considered the initiators of change in this development. As such they are the *independent variable* of the model. The main opportunity is the recognition for sustainable change of international and national policymakers. This includes environmental protection (Dell & Rand, 2001;

Johansson & Turkenburg, 2004). This is substantiated by the respondents in the Q-Methodological research. Especially their qualitative feedback clearly states that the time is ripe for sustainable change. Furthermore, they state that it will be the role of policymakers to provide the initial push and guidance.

However, the role of policymakers for is indirect. Their attention for the power grid in general, and their knowledge of storage applications in particular, is low (Diekman, 2017; Hoogma, 2017; Kern & Smith, 2008; van de Poll, 2019; Verbong & Geels, 2007). The main barriers are the lack of a long-term vision and the regulatory framework related to the issues of energy and environment. These are vague and subject to change. Although the implementation of storage applications is not specifically mentioned, their legality can be questioned (Crabtree et al., 2011; He et al., 2011; Heinen, 2018; Hoogma, 2017).
The role of policy is thus to create a level playing field between *hybrid systems* and fossil-based electricity generation. This will enable the update of storage applications in the market environment (González et al., 2004; Kelly et al., 2009; van Dril, 2018; "*Position Paper rondetafelgesprek tweede EU-mobiliteitspakket*", 2018; Weeda & Gigler, 2018).

The current competition between fossil and renewable energy, and thus between *hybrid* and fossil flexibility, is not solely due to the costs of the generation systems themselves. According to multiple sources, the *marginal costs* of generation of renewable electricity and of *hybrid systems* are lower than that of fossil based energy (de Wit, Ron, 2018; Oldenbroek et al., 2017, 2017). This would suggest that the market would choose for the renewable option. However, new forms of energy require system changes with long payback periods, while these changes are not required for the current fossil-based systems. One should however not forget that the current electricity system was built with governmental help, as described in chapter 2, giving these systems an unfair competitive advantage.

Economic forces will become the main driver for the adoption of change once policy enables the development of a viable business case. As such, the influence of economic factors is currently *mediating.* There is a lot to be gained with such applications in the market (Hall & Bain, 2008; Lund & Münster, 2003). The main barrier for their implementation is the initial investment required (Gottwalt et al., 2011; Haspels, 2018; Türkay & Telli, 2011; van der Stelt et al., 2018).
Both the role of the market as instrument of change and the barriers raised by investments are substantiated by the respondents. However, respondent 4 believes that the competition within the market environment with a focus on profit will never enable true equity and sustainability. Therefore, the energy sector should be removed from the market environment.

Technology is considered to be a *moderating variable*. Nor political, nor economic gains will enable the development of the *ideal state* if technology cannot cope with the requirements to achieve this. Both literary sources and the respondents agree on the necessity, and the theoretical capability, of storage applications. The maturity of the technology is however debatable, as claims vary from 'already feasible' to 'future options' (Dunn et al., 2011; Frois, 2017; Hovsapian, 2017; Mohanpurkar et al., 2017; Oldenbroek et al., 2017).

The societal aspects are placed outside the diagram. They are considered to be *moderating* all aspects, both in a positive and negative way. The societal call for environmental protection leads to political and economic development in favour of the initiation of change. However, society is mainly guided by costs, as these are tangible while the benefits are not (Dell & Rand, 2001; Gottwalt et al., 2011; van de Poll, 2019; van Dril, 2018). As such, the positive influence of society with regard to environmental change is undone if the price for the end-user associated to this development is not limited *compared to the current price of energy*.

The above is elaborated and substantiated by discussing the answers to the six Research Sub-Questions in the next sections.

6.2 Research Sub-Questions 1 and 4

The research sub-questions 1 and 4 investigate the roles and benefits of integrating electrical storage applications in the power grid.

There is agreement between the information deducted from literary sources and the result of the Q – Methodological research. The implementation of storage applications is needed to deal with the increasing loads and variability on the power grid. This main driver is the recognition of environmental protection, which leads to the integration of renewable electricity on the power grid. There is however a deficiency in how the main roles of storage applications is deducted from literary sources and is perceived by respondents.

The current power grid is developed to support the generation of electricity through conventional and fossil-based power plants. In turn, fossil fuels have the benefits of having high energy density and to be easily storable and transportable (Crabtree et al., 2011; Dell & Rand, 2001; Gottwalt et al., 2011). The controllability of conventional power generation thus limits the imbalances on the power grid and eases energy management. Their flexibility is already used to mitigate with the variability of renewable electricity generation (González et al., 2004; Vazquez et al., 2010). Furthermore, regardless of the capabilities of the power grid, research shows that it is highly unlikely that the increasing electricity demand can even be met through renewable generation in highly populated countries. Furthermore, the use of electricity is only a fraction of the aggregated energy consumption (MacKay, 2013; van Wijk & Verhoef, 2014; "*World Energy Consumption Statistics | Enerdata*", n.d.). This leads to:

Proposition 1: The main role of electrical storage applications in general is to enable electricity conversion to a renewable energy carrier in order to substitute fossil-based fuels.

This will ensure clean energy for all sectors without the loss of flexibility which is now provided by fossil fuels. A second issue is that the capabilities of the power grid will remain limited. As such, load levelling will remain a challenge, regardless of the investments in flexibility. The transport of energy through pipes is easier and cheaper. Furthermore, 98% of the built environment in the Netherlands is already coupled to the natural gas grid (Hoogma, 2017; van der Meijden, 2017; Lund & Münster, 2003; "*Position Paper rondetafelgesprek tweede EU-mobiliteitspakket*", 2018; Weeda & Gigler, 2018). This leads to:

Proposition 2: The main role of electrical storage applications on network management level is to enable the integration of the power grid with other energy networks.

These propositions are not supported by the respondents. They attribute low to mediocre scores to the statements applicable to them (statement 2, 3, 7 and 8 in Q-Sort 1). Instead, their focus is strictly on the power grid and the need to separate supply and demand of electricity. This can however be attributed to the unclear description of the term's *storage* versus *conversion,* and the focus on the power grid within the survey. As such, the benefits of storage applications as described in the proposition require a holistic view on energy management which is, arguably, not induced by the statements and questioning applied in the format of the Q-Methodological research used for this thesis.

6.3 Research Sub-Questions 2, 3, 5 and 6

The research sub-questions 2, 3, 5 and 6 serve first to gather the various factors influencing the implementation of storage applications. Subsequently, they explore their level of obstruction.

The Political and Regulatory Factors

Proposition 3A: Current policy and regulations oppose the implementation of storage applications in the Dutch Power grid but;
Proposition 3B: Policy and regulations can be the main driver for the implementation of storage applications in the Dutch Power grid.

These propositions have already been by literary sources in *section 6.1.* The opinions of the respondents are not straightforward. The quantitative results of the Q-Methodological research show disagreement with these propositions. However, as discussed in chapter 5, the qualitative feedback provided by the respondents suggests that the statements illustrating policy and regulations are not ranked by the *current* frame of reference, but by their *anticipated future* influence. As such, based on the qualitative data, propositions 3A and 3B are substantiated by the respondents.

The role of policy is to act as a change agent. It is twofold.
First, it should enable the initiation of change to support the transition towards the *ideal end-state* as defined in chapter 1. For this, government will need to:

Develop and communicate the *desired ideal end-state.* This involves providing a long-term and holistic vision on sustainability.
It should act as sponsor. Despite the historic aim of creating a market driven environment, this involves expressing a clear preference towards, and providing clear advantages for, desirable technologies.
It should enable the prohibition of technologies that do not adhere to the *desired ideal end-state.*

The second role of government is to create a level playing-field within all aspects of the supply chain of energy and applicable to all sectors by:
Defining measurable conditions to adhere to the desired developments and to watch-over its execution.
The integration of costs and benefits in the price of network usage to energy suppliers.
The integration of the costs of negative externalities, such as environmental damage, to the different energy sources and generation methods.

All the above are currently missing and are thus barriers. (Heeger, 2007; Hoogma, 2017; Johansson & Turkenburg, 2004; Kern & Smith, 2008; van Dril, 2018; van Swaay, 2018; Verbong & Geels, 2007; Weeda & Gigler, 2018)..

The role of policy, as described above, is filtered from literary sources and presentations specifically discussing the development of the Dutch and European energy sector. It is however striking how these requirements are similar to the theories of developments and changes of market environments discussed by Rogers (1983) and Moore (1993).

The Economic Factors

Section 6.1 describes that the *marginal costs* of electricity from renewable generation and *hybrid systems* are lower than through fossil-based generation. The value of this electricity is however reduced by the capacity of the grid to enable its distribution to the consumer. This creates volatility in the prices of renewable electricity , and hence affects its trads (González et al., 2004; Johansson & Turkenburg, 2004). As such, the implementation of storage applications could lead to substantial profits in the market environment. This is however only possible if these applications can capture the financial benefits associated to all facets of electricity, which involves its generation, the network management and its trade (He et al., 2011; Lund & Münster, 2003). However, this is opposed by regulations (Crabtree et al., 2011; Heeger, 2007). Furthermore, currently no single storage technology is capable to meet all the requirements of systems services. This increases the required investments. This is illustrated and substantiated in *Figure 11* in the report and *Table 2* in *appendix 3*. As previously discussed in section 6.1, from a financial perspective only, the development of a viable business case for *hybrid systems* is mainly thwarted by the initial investment costs. This leads to:

Proposition 4: There is currently no viable business case for the integration of storage application for any individual stakeholder in the electricity sector.
Proposition 5: The fragmentation of the business environment of the electrical value chain negatively influence the implementation of storage application for current stakeholders.

The scores attributed to the *statements* 7 to 12 in the second Q – Sort, supplemented with the qualitative feedback provided by the respondents, support *proposition 4*. The specific scores attributed to, and the ranking of *statement 9* further substantiates the claim that particularly the high investment costs are a barrier.

There are different beliefs on the true costs of storage and *hybrid systems.* Even academic research mentions different numbers (Jorgensen & Ropenus, 2008; Oldenbroek et al., 2017). As such, one should consider whether the economic barriers of storage applications are valued accordingly, or that the view is too pessimistic for erroneous reasons.

The scores and qualitative feedback attributed to *the statements* 25 and 34 do not substantiate, nor take distance from *proposition 5*.

Multiple sources claim that the lack of a viable business model is merely due to the failure of regulations to fully capture all the costs and benefits into the market price of electricity (Crabtree et al., 2011; González et al., 2004; Gottwalt et al., 2011; Johansson & Turkenburg, 2004; Koç, 2015a; van Dril, 2018). This leads to:

The implementation of storage application is economically unviable due to the failure of the market to capture the costs of:
Proposition 6A*: Network development and management (and the damage attributed to its failure);*
Proposition 6B: *Environmental damage attributed to harmful emission of electricity generation;*
In the marginal market prices of electricity.

The respondents perceive that the low prices of fossil fuels are a barrier for the implementation of alternative technologies. This is shown in the results of *statement* 36. However, they also attribute mainly positive and mediocre scores to the *statements* 5, 31 and 35. It seems the respondents do not believe the competitive position of storage applications would change if the full costs of network management and environmental protection would be integrated in the prices of electricity.

The Technological Factors

The technological capabilities of storage applications to perform system services is deducted in the creation of *Figure 11* in the report and *Table 2* in *appendix 3*. Furthermore, pilot projects in California substantiate the technological feasibility (Frois, 2017; Hovsapian, 2017; Mohanpurkar et al., 2017). This leads to:

Proposition 7*: It is technologically feasible to reach the desired ideal end-state via the application of storage and conversion applications on the power grid.*

The respondents attribute positive scores to the technological feasibility. This is shown by the results of *statement 19* and 20. As such, the result of the Q-Methodological research substantiates proposition 7. The results of the first survey however indicates that the respondents attribute the scores based on the anticipated capabilities of storage and not on the current maturity of the technologies. Academic papers and respondents both perceive the availability of raw materials (*statement 23; Evans et al., 2012; Hall & Bain, 2008)* and the level of knowledge and qualified manpower (*Statements 21* and 22; "*Digitalization and the future of energy storage*", 2019) as an issue requiring attention.

This chapter previously discussed and substantiated how historic developments in policy and regulations and the current composition of market forces influences the competition between fossil-based and *hybrid* flexibility. This leads to:

Proposition 8*: The technological development of storage and conversion applications is hampered by the lack of clear end-state.*

Which circles back to propositions 3 to 6.

This proposition is deducted from the other propositions. Whether this specifically affects the development of storage applications is not conclusively described in academic literature, nor is it emphasized by the respondents. As such, proposition 8 is not substantiated, nor discarded, by the findings of this research.

The Societal Factors

Section 6.1 discusses that society will not simply accept higher personal costs. As such, the start of the implementation in the market will require external guidance and financial incentives. This is illustrated by respondent 1: *'When it comes to keeping the social costs as low as possible, namely by making the right trade-off between storage and strengthening the network, the government should also have a say in this. The network manager could invest in storage instead of increasing the network, but government should make a contribution, so that fewer costs are socialized by the network operator.'* This leads to:

Proposition 9: The societal recognition for environmental issues is beneficial for the implementation of storage application in the power grid but;
Proposition 10: The development of a viable business case is instrumental to enable full societal support for their adoption.

6.4 Conclusion

The execution of a PESTLE analysis in combination with Q – Methodological research would benefit the discussion with regard to the development of the Dutch power grid. Moreover, it would be beneficial during all discussions in which a broad set of stakeholders with different interests are involved.
First, the PESTLE analysis forces all actors to consider the subject from different angles. Furthermore, this leads to information that would otherwise not have been used, or even known. Two of the respondents indicated they never considered the usage of storage for the integration of multiple energy infrastructures nor the necessity to do so. Another respondent did not realize that the legal status of electricity storage bycurrent stakeholders is vague. The benefits of storage applications are therefore not valued correctly.

The subsequent Q- Methodological research provides insight into how certain actors are influenced by which factors. This enables a better understanding of the differences between perspectives, which often originate on a deeper level. Furthermore, this insight can also prevent actors from forming an opinion based on the incorrect interpretation of data. Even the multiple academic sources used for this thesis sometimes provide contradictory information. For example, the implementation of storage application is not considered by some actors due to its high prices in comparison with fossil-based energy. Meanwhile, other actors believe the *marginal*, and some even the *levelized,* costs of *hybrid systems* are comparable or lower than that of fossil-based generation. In turn, these actors run into other barriers not perceived by others. It is very important that decisions are made to work towards goals that are recognized by everyone, using complete and correct information that is interpreted in the same way by everyone. The results of this Q-Methodological research raise the question whether this is the case. The combination of Q – Methodological research and a PESTLE analysis can enable this process.

The Dutch power grid will not cope with the increase in demand of electricity. The integration of renewable generation worsens the situation. The implementation of storage applications is therefore instrumental. Mitigating with the anticipated challenges by aiming for behavioural change, or by extending and strengthening the power grid, is not a viable option. Furthermore, the Dutch geography, the meteorological conditions and population density will not enable the renewable generation of ample energy to provide in the national need. As such, it is time to broaden the topic from renewable electricity, to renewable energy. The creation of a clean energy carrier through indirect storage would allow for the same flexibility currently provided by fossil fuels. It would enable conventional electricity generation, which in turn would greatly reduce the balancing challenges on the grid. Other forms of local storage will probably still be needed, but to a lesser extent. It is therefore imminent to look into the anticipated problems and solutions in the broadest possible sense.

The required developments in the energy sector should not be left to market forces, nor should it be steered by societal demand. Both are too much driven by profit and low prices. Change must be initiated and guided by clear policies and regulations. However, policymakers are also still driven by 'old-fashioned economic thinking'. Decisions are often made based on biased data and using cost-benefit analyses. The implementation of these decisions is only possible with long lasting support from society. Unfortunately, the costs are tangible for the current voters, while the benefits of change will be for their progeny. This creates too much flexibility to 'compensate' the use of energy and its emissions through other and cheaper means. It makes sustainability only a paper reality. Even worse is that a number of policymakers in the Netherlands openly criticize the controlling function of judges, or the reliability of research institutions, when their findings do not suit their policy.

There should be no room for doubt: the use of energy should no longer lead to environmental damage, regardless of the outcomes of so-called cost-benefit analysis. As such, fossil-based energy must be phased out.

6.5 Future Research

In section 6.4, a number of conclusions are drawn. Addition research is needed to substantiate, or discard, the claims made.

As discussed previously, the response rate for this survey is to low to correctly illustrate the perspectives within the electricity sector. Regardless of this limited response rate, the results show discrepancies in the way experts perceive the role of storage and the influence of external forces. Moreover, it illustrates how information is not evenly distributed between, or understood by, the respondents. This calls for a correct execution of this, or comparable, research to investigate the topic at hand. An example is provided by Cuppen et al. (2010), who illustrate the various perspectives between the stakeholders with regard to the use of biomass in the energy sector. Kropman (2019) shows how, in the recent negotiations with regard to environmental change, stakeholders and information still do not correctly represent the various perspectives in society.

In the literature review, the delineation of scenarios clearly shows the various applications of direct versus indirect storage. It explains how the choice for one reduces the need for the other. Furthermore, the research show that it is hard to truly value the benefits of storage. This is also clearly stated in the conclusions. Therefore, research is needed to assess the efficiency of generation methods, storage applications and *hybrid systems* from an energetic and environmental point of view.

Energetic point of view

The energetic perspectives can be investigated through *Net Energy Analysis*. This analysis enables the calculation of the *Energy Returned on Investments* (EROI) and *Energy Stored on Investments* (ESOI). As such, it provides a ratio of the generated or stored energy over the lifetime of a system, compared to the energy used for its construction and operations. These ratios can subsequently be used to calculate the $EROI_{grid}$, which is the ratio of energy that is actually provided to society, compared to the energy used for its construction and operations. This would enable to compare energy systems from a technological perspective instead of financial perspectives. Furthermore, it would enable to assess when it is more beneficial to implement storage applications, strengthen the energy infrastructure or to accept the temporary curtailment of energy generation (Barnhart et al., 2013; Pellow et al., 2015).

The effectivity of energy systems is often assessed from a limited point of view. For example, the implementation of large generation facilities for the production of renewable hydrogen is often discarded due to the loss of energy during the initial conversion of wind energy to molecules. Van Wijk and Verhoef (2014) introduce a supply chain approach to value the effectivity of energy systems. This approach calculates the ratio between the final and primary energy.

Environmental point of view

The ratios and supply chain analysis described above could subsequently be used to analyse the environmental impact of energy generation. After all, it is possible to calculate the emission associated to the conversion of one unit of fossil energy. As such, it should be possible to calculate the ratio between the emissions associated to the construction and maintenance of a system, versus the emissions associated to its operation. This would help to determine when it is viable to invest resources to develop an energy system from the point of view of environmental sustainability.

Furthermore, the literature review and the results of the Q – Methodological research shows that there are doubts with regard to the theoretical capabilities of storage and *hybrid* systems. As such, practical research is needed to substantiate the anticipated benefits of such systems. Researchers would do well to look at the case studies described by Mohanpurkar et al. (2017) and Frois (2017). The first describes the usage of an electrolyser on the power grid of California to perform Power quality management. The second study compares the effectivity of batteries, Regenerative Hydrogen Fuel Cells and Fossil-based systems to perform energy management in Tehachapi, California.

6.6 Research Limitations and Lessons-Learned

There are always limitations to the level of truth, relevance and usability of the results of a research. This need not affect the vigour of the end-results as long as they are recognised and taken into account.

Q- methodological research is exploratory in nature. Since viewpoints and opinions are not consistent across time, it does not provide a timeless outcome, as (Cuppen et al., 2010). This research thus only provides a temporary snapshot, which is subject to change. This also illustrates the strength of Q-Methodology, as a repetition of the Q-Sorts can identify changes in perspectives among actors. This enables the monitoring of decision-making processes in order to adjust accordingly. This thesis however only provides one iteration. The use of multiple iterations within Q-Methodology is discussed in more detail in the book and paper on the subject written by Watts and Stenner (2005, 2012). Reading these documents should be the starting point for any researcher planning to execute Q – Method.

The process of reaching *saturation,* as described in *Chapter 4,* does not guarantee the concourse covers the full range of viewpoints. Information can be overlooked or wrongly discarded. Furthermore, the choice to compile the concourse in an unstructured manner does not guarantee an unbiased composition of statements. Preferably, the creation of the Q – Set is executed in close cooperation with stakeholders and outsiders. The different ways to develop the concourse and subsequent Q – Sets, as well as their benefits, disadvantages and scientific validity, are discussed by Watts and Stenner (2012). The usage of iterative discussions is part of the exploratory *Delphi* research method. The introduction of a Delphi poll can enable a collaborative approach to derive the statements for the Q – Sets. This guarantees the information remains up to date, is complete and is correctly translated into statements. The combination of Q – Methodological research and a Delphi poll is used by Wallis et al. (2009). This approach does require more time and may thus be not usable for a master's Thesis.

For unknown reasons, an extensive number of surveys was lost. As such, the set of respondents does not adequately represent all stakeholders and their viewpoints. Therefore, the conclusions are <u>not</u> generalizable. As discussed in *Chapter* 4, as a rule of thumb, each perspective should be derived from 6 – 8 respondents (Watts & Stenner, 2012). Therefore. the statistical analysis executed for this thesis is not statistically relevant. For this thesis, a business ecosystem, described by Moore (1993), was used to map all actors involved in the electricity sector. It was subsequently deducted that these actors operate within different market environment, which leads to different costs and benefits in case of change. As such, the Q-Sorts for this thesis would preferably have been executed by a minimum of six respondents from each element of this ecosystem, as shown in *figure 6*.

The Q-Methodological survey was executed online, instead of face-to-face. The latter is recommended. Q-Methodological research is not common. It is often a new experience for most respondents. This justifies the presence of the researcher in order to provide additional explanation. Furthermore, although the results of the Q-Sorts are considered and analysed as quantitative data, the emphasis of the study aims to measure the point of view of respondents on the subject at hand. As such, the researcher should be present to discuss the execution of the survey with the participants, as this provides important qualitative information. (Den Boer et al., 1994; Watts & Stenner, 2005, 2012). The disadvantage of an online tool is reflected in this very report. As discussed in chapter 5, the respondents did not sort all statements according to the same frame of reference. Furthermore, the multiple opportunities of storage applications are not valued accordingly by all respondents. Respondent 3 - *'The integration of multiple energy infrastructures and sectors sounds interesting. However, I do not know how storage could achieve this.'* As such, it is likely that the sorts would have been executed differently by the respondents if questions could have been asked during the execution.

6.7 Management of Technology – Thesis Relevance

The Research Gap and the Academic Relevance are closely related to the subjects of *Management of Technology*. The subject at hand, the implementation of electrical storage applications, is innovative. It will require careful management by a change agent, from a point of view of technology, market and policy and regulations.

Although the application of batteries and other systems has been used for a while, the scale of the usage of storage as balancing mechanism is different. This will require major changes to the associated infrastructure and will change the roles of the stakeholders. Since no standards are chosen yet, both commercial and utility companies are currently faced with the decision on which system to use and of when to start implementation.

The topic is also interesting from a market perspective. Storage applications are in great part considered as complimentary to renewable electricity generation systems. These *hybrid systems* should enable the same flexibility as the current dominant paradigm in the sector, which is based on fossil fuels. Since the business model of the major energy companies is still based on fossil systems, investing in innovative hybrid technologies constitute a market cannibalism approach. Fossil energy is however increasingly criticized due to the associated negative externalities. As such, the current major stakeholders are taking great care to monitor the developments in order not to rock, nor to miss the boat.

This leads to the role of policy and regulations. The societal pressure for environmental protection forces policymakers to take measures in order to steer the market forces towards sustainable change, regardless of financial cost-benefit analysis.

These three aspects; technology development, market development and the role of change agents are all relevant to *Management of Technology*. The research design, combining a PESTLE Analysis and Q-Methodological Research, provides insight and enforces the development of knowledge in all relevant factors associated to these aspects.

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Appendices

Appendix 1 – General

Appendix 1.1 – List of Abbreviations

AFM	Autoriteit Financiële Markten
APX	Amsterdam Power Exchange
CAES	Compressed Air Energy Storage
DDA	Dutch Datacenter Association
ECN	Energie Centrum Nederland
EROI	The (electrical) Energy Returned On Investment.
ESOI	The (electrical) Energy Stored On Investment.
FEC	Front End Controller
IEA	International Energy Agency
LCOE	Levelized Cost of Electricity
MEP	Ministeriële regeling Milieukwaliteit elektriciteitsproductie
NEA	Net Energy Analysis
PCA	Principle Componnent Analysis
PHS	Pumped Hydroelectricity Storage
PV-Systems	Photovoltaic Systems --> Solar (Power generation)
REB	wet Regulerende Energie Belasting
RES	Renewable Electricity Systems
RHFC	Regenerative Hydrogen Fuel Cell
SME	Small and Medium sized Enterprise
UPS	Uninterreuptible Power Supply
WON	Wet Onafhankelijk Netbeheer

Appendix 1.2 – List of Definitions

Term	Definition used in thesis
Actual State	The current Dutch electrical infrastructure.
Balancing Market	The market of *operating reserve* in order to enable the adjustment of power supply to meet demand. Generators can offer reserve power in this market. When generators fail to meet their share of power generation, power is bought from other generators in this market, see *top-up prices*.
Bilateral Market	The market in which large consumers, electricity traders and supply companies engage in long-term contracts. The contracts are confidential. 85% of power generation is traded in this market.
Capacity Factor	The capacity factor is a unitless ratio that measures the effectivity of any electricity generating installation by dividing the actual measured output by the theoretical maximum output in a given time period.
Conventional Power Generation	The production of electricity converted via a combustion process of a Primary Energy Carrier, a fuel, like oil, gas, waste or biomass.
Conventional stabilisation market	The smoothing of the output and fluctuation of conventional market.
Cycle life	The number of charge and discharge cycles before a battery starts to reduce in performance and needs replacement in order to fulfil its envisioned task. (See also (system) lifetime)
Desired Ideal State	The development of an electrical infrastructure that enables a sustainable energy system without compromising on its robustness.
Decentralized production sites	Electricity generators located outside of the original power grids.
Depth of Charge	The relative amount of energy discharged from the battery compared to its design maximum energy capacity.
(in)direct storage	With direct storage, a single system converts and reconverts electrons for storage and later usage. With indirect storage, a system converts electrons to molecules, a second system provides storage and a third system reconverts the molecules back to electricity.
Electricity efficiency	The relative output of electrical energy compared to the input of *Primary Energy*.
Energy Arbitrage	Earning a profit by charging electricity storage during low demand and selling at higher prices when demand is high.
Energy Capacity	The amount of energy that can be stored in a system, given in Watt/Hours. (See *Power Capacity and Energy-to-Power ratio)*

Term	**Definition used in thesis**
Energy Cost	The capital building cost of energy (€/kWh).
Energy Intensity	Lifecycle cost of energy production per unit of energy delivered to society. An high energy intensity ratio means a generator is inefficient from an energetical point of view. It provides little energy to society compared to the costs in
Energy-to-Power Ratio	The amount of time a system can deliver a certain power (See Power and Energy Capacity)
Energy Value	The costs avoided of generating electricity from alternative sources to meet demand in times of shortages.
Environmental Protection of a energy system	A energy system in which society is protected from the associated harmful emissions and consequent climate change.
Equality Constraint	The boundary conditions forcing power line operators to maintain *Power Quality* while the quantity of electrical energy fed to the grid by the various generators must equal the sum of the overall demand and the transportation losses. Failing to maintain this constraint can lead to failures.
EROI	The amount of energy generated by a system over its lifetime compared to the energy required to produce the system.
ESOI	The stored energy returned by the device over its lifetime compared to the energy required to produce the device.
Frequency regulation	The constant second-by-second adjustment of power to maintain the grid frequency at 50 Hz.
Front End Controller	The FEC enables the communication and integration between the grid operations and the controller of the electrolier. It continuously monitors the grid and generates the control signal to the controller of the electrolyser to optimize its setpoint to provide balancing capability (optimization of power quality) and produce hydrogen at the lowest price.
Full Chain Efficiency	The efficiency from well to power outlet
Generation Capacity Value	The fixed generation costs avoided by allowing the shutdown of conventional power plants.
Institutional factors	The full range of opportunities, regulations, business models and ideas that steers the way in which technologies and processes are embedded in and accepted by society.
Interconnectors	The physical structures enabling the flow of energy between networks.
Hybrid Energy Systems	Systems integrating several energy production structures in combination with storage units.
(System) lifetime	The amount of actual time a system can operate on average before replacement. (See also *Cycle Life)*

Term	Definition used in thesis
Levelized Cost of Electricity	The holistic costs of a kWh of electricity levelized over the timeline of the plant.
Load Factor	The load factor is comparable to the capacity factor both with regard to loadings on the grid. The ratio is calculated by dividing
Load Levelling	The use of electricity stored during times of low demand or overcapacity of the grid during peak demands. It reduces the need to draw electricity from peak power plants and assists when the grid capacity is not able to transport the required power to the client.
Net Balance	The continuous perfect balance between supply (production) and demand (use) of electricity. The need to maintain this balance leads to the *equality constraint* in the electrical infrastructure.
Net Energy Analysis	Comparing the amount of energy delivered to society to its energy consumption including manufacturing over the lifetime of technologies.
Oligopoly	A situation in which an economic product or service is provided by a limited number of suppliers, leading to disproportionate market forces.
Operating Reserve/Reserve Capacity	The reserve power generators maintain to enable compensating the loss of another generator on the grid. As such, during normal operations, generators run below their rated value and ideal set point, leading to additional use of fuel. As such, the use of a unloaded *spinning reserve* can be beneficial.
Outsiders	*Stakeholders* who have alternative visions of (changes in) the functioning of a sector, but are currently not sufficiently involved or influential.
Overall Energy Efficiency	The ratio of the energy returned by the system over its lifetime divided by the total input of energy in the system over its lifetime. Not to be confounded with the *Round-trip efficiency.*
Peak Shaving / Peak capacity management	The consistent and reliable reduction of peak loads within a defined region or location on the grid.
Photovoltaic Systems	Power systems based on solar energy.
Power Capacity	The amount of energy a system can release at any given time, in Watt. (See Energy Capacity and Energy-to-Power ratio)
Power Cost	The capital building cost of power (€/kW)
Power Quality (Management)	The smoothing of power quality on nano- and millisecond scale by maintaining electricity voltage and frequency levels within strict boundaries. See *Frequency Regulation.*

Term	**Definition used in thesis**
Primary Energy	*Primary Energy* is the original form of energy from where the energy used by the end-user is derived. This can originate from available energy carriers (fuels) such as oil, gas, waste and biomass, or from natural energy such as solar, tidal and wind power. Primary Energy contains a measurable quantity of energy, either readily available (e.g. wind) or stored in its chemical composition (e.g. fuels). As such, the Primal Energy of an energy source is the theoretical maximum amount of energy that can be extracted and used by the end-user if there were zero losses.
PV-Partij	The entities tasked to provide the daily planning of anticipated generation and usage of electricity, as well as the required transmission and distribution capacity on the infrastructure.
Ramping	The increase of decrease of power generation and affiliated fuel consumption to meet the Net Balance.
Regenerative Hydrogen Fuel Cell	The combination of an electrolyser, storage and fuel cell in order to perform the full cycle of indirect storage.
Reserve Capacity	See operating reserve
Renewable Electricity Production/System	An energy generating resource that is replaceable by a natural process in such a way that its energy usage does not lead to its depletion.
Robustness of a energy system	The ability of a (energy) system to avoid malfunctioning when a fraction of its elements fails as a result of deliberate attacks or random failures that limit the ability of the system to accomplish its tasks
Round-trip efficiency	The efficiency of the whole process of converting, storing and reconverting electricity by a system. Thus the ratio between electricity in and electricity out for a single storage, where the Overall Energy Efficiency is calculated over the lifetime of a system.
Saturation (point of)	The moment no new perspective can be filtered from any new source of information on the topic at hand.
Slew Rate	The change of voltage, or current, or any other quantity given in unit of time. Some systems affiliated to electricity may specify minimum and maximum limits of slew for both input and output.
Spinning Reserve	Generation capacity that is on-line but unloaded and can response immediately in case of primary generation or transmission failures. The use of storage can reduce the need to maintain operational spinning reserve by conventional generators.
Spot Market	The short term market of electricity. Trade is performed for the next day and on a hourly basis. The prices of electricity in this market are highly volatile. The Dutch Spot market is the APX, owned and operated by the TSO TenneT. Also see *bilateral market* and *balancing market.*
Stakeholder	An actor involved in, affected by, knowledgeable of, or having relevant expertise or experience on the issue at stake.
Sustainable energy System	A system which enables economic growth and energy security while providing *environmental protection*
Transmission and Distribution Network value	The costs of avoiding investments on the power grid by enabling matching supply and demand of power.
Top-Up prices	The application of higher prices for electricity between power generators when one fails to meet its share of power and thus needs to buy additional capacity from competitors.

Appendix 2 – Domain

Chapter 2 describes the external forces as depicted in the PESTLE analysis within the frame of reference of the Dutch power sector only.

Figure 1 - Timeline of EU and National Policies and Regulation with Regard to Energy and Climate

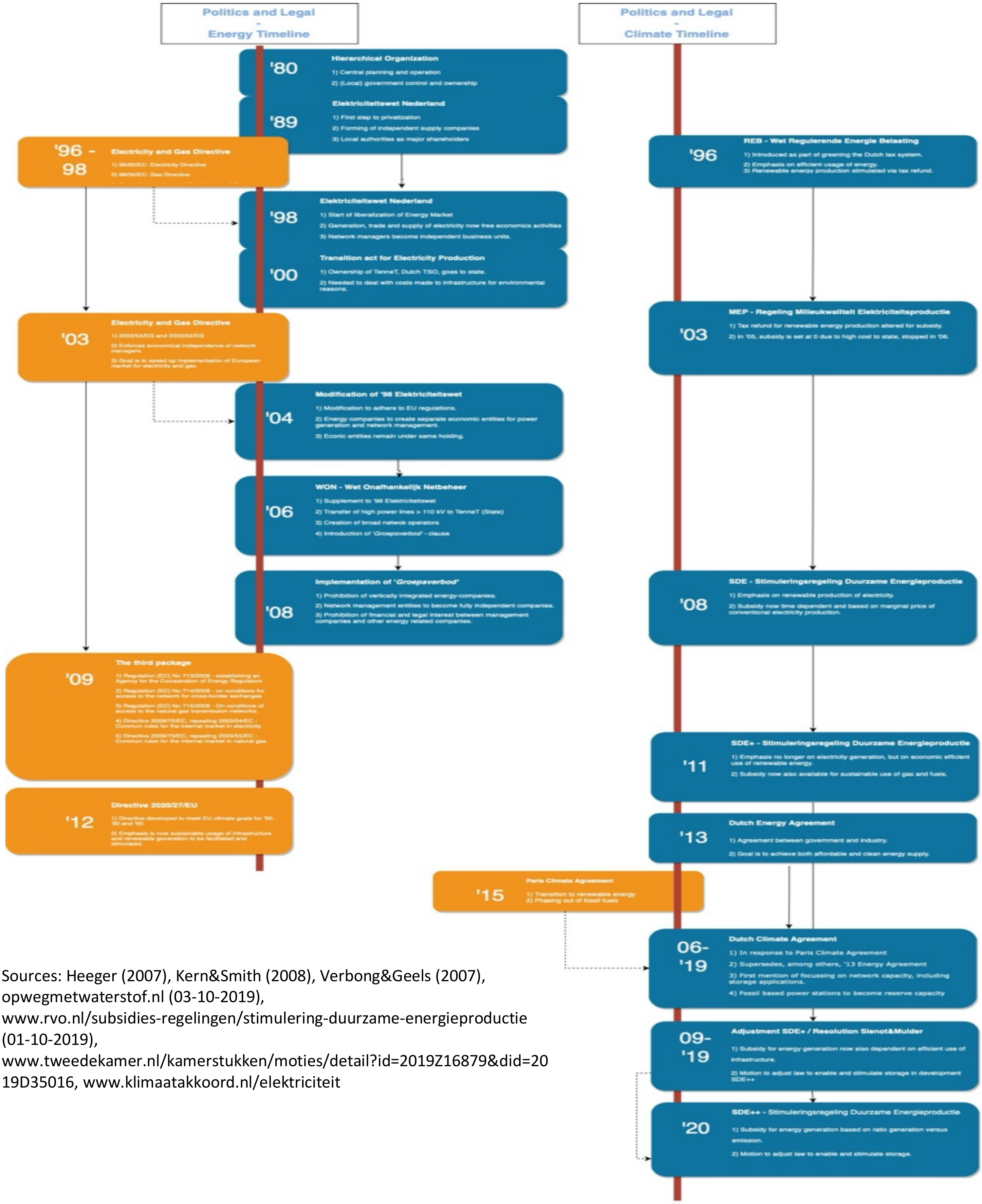
This figure illustrates an extensive timeline of the various national and supranational regulations and underlying policies on the topics of Energy and Climate. It serves as background information to the text in chapter 2 on the influence of policy on developments in the Dutch Power grid.

Figure 2 - Timeline of Economical and Market Development of Network System Operators

This figure illustrates an extensive timeline of the changes in the market environment associated to both electricity generation and network management. To a large extent, this development was driven by policy, as described in chapter 2 and illustrated in Figure 1. It serves as background information to the text in chapter 2 describing the development in the market starting from a limited number of local and government owned vertically integrated energy companies to the market environment as depicted in Table 1.

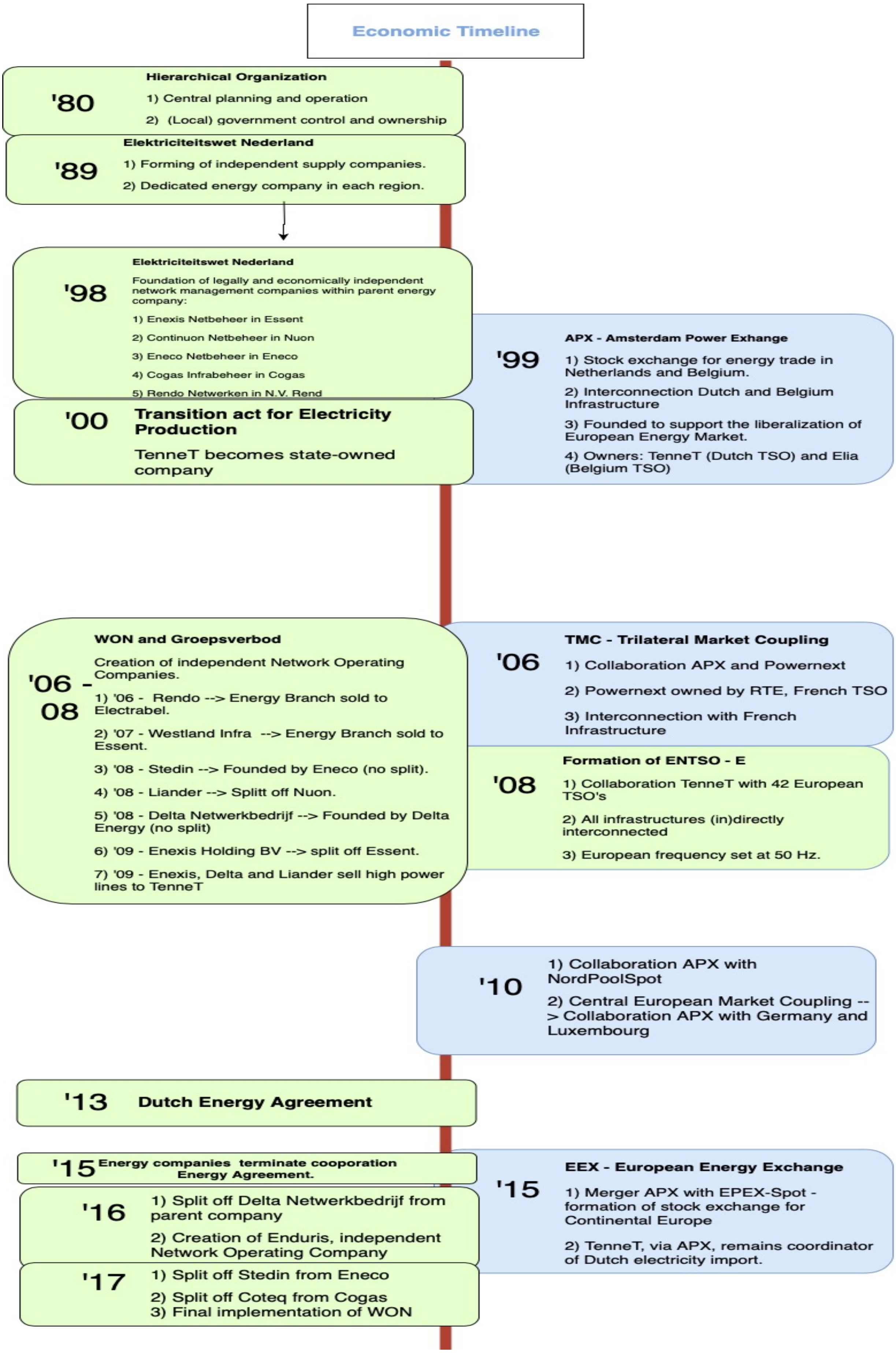
Table 1 - Stakeholders involved in the Dutch Electricity Sector

The current market environment associated to the Dutch Electricity sector. It serves to illustrate both the increase in number of stakeholders, the fragmentation in the supply chain caused by the various policies, with emphasis on the *'Splitsingswet'*. Moreover, it shows how the sector is divided in market-based companies in full competitive and monopoly environment, governmental owned companies and government driven companies with national and local monopolies.



Sources: Heeger (2007), Kern&Smith (2008), Verbong&Geels (2007), opwegmetwaterstof.nl (03-10-2019), www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie (01-10-2019), www.tweedekamer.nl/kamerstukken/moties/detail?id=2019Z16879&did=2019D35016, www.klimaatakkoord.nl/elektriciteit

Figure 1 - Timeline of EU and National Policies and Regulation with Regard to Energy and Climate



Sources: Heeger (2007), Kern&Smith (2008), Verbong&Geels (2007), opwegmetwaterstof.nl (03-10-2019), www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie (01-10-2019), www.tweedekamer.nl/kamerstukken/moties/detail?id=2019Z16879&did=2019D35016. www.klimaatakkoord.nl/elektriciteit

Figure 2 - Timeline of Economical and Market Development of Network System Operators

Table 1 - Stakeholders involved in the Dutch Electricity Sector

Business Ecosystem affiliated to Dutch Power Generation								
Energy Companies	Power Generators (#				Power Infrastructure		Electricity Suppliers	
Companies (#200)	Fossil Based (#24)	Energy Carrier/Nominal Generation (MW)	Renewable based (#x)	Type / Nominal Generation (MW)	Transmission Operators (#1)	Distibution Operators (#7)	Business Market only (#12)	Retail Companies (#47)
Exxon Mobil	**RWE**	**Coal / 1860** **Biomass / 240** **Natural Gas / 2738**	Vattenfall Nuon Delta	Hydro / 25,8 Offshore Wind / 1520 Offshore wind / 54 Offshore wind / 600	TenneT	Coteq	Groene Stroomfabriek	**Innogy** - Essent / EnergieDirect
Royal Dutch Shell	**Engie**	**Natural Gas / 3989**	Dong Energy	Offshore wind / 752	ENTSO-E (#43)	Enexis	Scholt	**Nuts Groep** - Budget Energie / NLE
Chevron	**Vattenfall**	**Coal / 630** **Natural Gas / 3325**	Eneco	Offshore Wind / 250 Offshore wind / 366		Liander	Energyhouse	**Eneco Holding** - Oxxio / Woonenergie / Eneco
Petrochina	**Eneco**	**Biomass / 50** **Natural Gas / 1576**	Shell	Offshore wind / 54 Offshore wind / 366		Rendo	Dvep	**Vattenfall** - Nuon / Delta / Powerpeers
Total	Uniper	Coal / 1070 (Biomass) Natural Gas / 528	RWE	Hydro / 11		Stedin	Total	Energie Concurrent - Greenchoice / Qurrent
BP	EDF	Natural Gas / 870	Tocardo	Hydro / 1.2		Westland Infra	Gazprom	Engie - Engie / United Consumers
	Riverstone	Coal / 800 (Biomass)	Onshore Wind				Innova	Pure Energie
	Rijmond Power	Natural Gas / 810 Garbage / 30 (Biomass)	Overall	900			van Helder	Easyenergy
	Nouryon	Natural Gas / 589	Pure Energie	Onshore Wind / - Solar			Endesa	Fenor
	BMC	Biomass / 32	Qurrent	Onshore wind / - Solar			ServiceHouse	Vandebron
	BECC	Biomass / 25	Greenchoice	Onshore Wind / - Solar			Main Energy	Ventum
	EdeA	Natural Gas / 231	HVC	Onshore wind			Hezelaer	Naked Energy
	Twence	Biomass / 25,4 Garbage / 59	Commercial Solar Parks					N.H. Energie Coop.
	Air Liquide	Natural Gas / 300	Overall	638				Zelfstroom
	Dow	Natural Gas / 277 Hydrogen / 92	Overall	2148				OM
	Castleton	Natural Gas / 427						Sapa Green
	Europoort Utility	Natural Gas / 24						Huismerk Energie
	Attero	Garbage / 123						Nieuw Hollands Energiebedrijf
	Omrin	Garbage / 20						DGB
	EPZ	Nuclear / 485						HVC
	HVC	Garbage / - (Biomass)						Anode
	Brouwer	Biomass / 1	Legend					Nieuwestroom
	Cogas	Biomass / 1.75	Fill color	Generators & Suppliers				Energie van ons
	BES B.V.	Biomass / 1.2	**Bold**	Commercial Monopoly (4-6 companies hold 70% of market)				Qwint
			Green	In development				Cleanenergy
								Vrijopnaam

Source: ECN.nl, monitoring Nederlandse Elektriciteitscentrales (update 12-08-2019), SDE+ Windernergie op Zee (update 9-09-2019), zonopkaart.nl, ECN.nl - Energieleveranciers en stroomproducenten (update 2018), www.forbes.com, www.tennet.eu, value.today - Energy Companies (Update 01-07-2019), GWEC Global Wind Report (2017)

Appendix 3 – Literature Review

Chapter 3 describes the role of external forces on the developments in the electricity and energy sector in general and the maturity of the various storage applications in particular. In varies from chapter 2 by broadening the scope to literature on market development and management of innovation in general. This is again structured conform the PESTLE analysis.

Table 2 - An overview of Key-Parameters of Storage Applications

In Chapter 3 – The Literature review, the *Figure 11* illustrates how none of the main storage technologies can meet the requirements to perform the systems services discussed in section 3.1. The key-parameters are discussed here and illustrated in *Table* 2. This includes their source references.

Table 3 - Q - Set 1: The Anticipated Roles and Utilities of Electrical Storage Applications

This table constitute Deliverable 1 – an extensive and substantiated list containing the main roles attributed to the implementation of storage applications in the power grid. This is filtered from the initial concourse, which is available on request, as well as all the substantiating statements referred to in the Q-Set.

Table 4 - Q - Sort 2: The Perceived Barriers and Opportunities with regard to the Implementation of Storage Applications

This table constitute Deliverable 2 – an extensive and substantiated list describing the various external factors influencing the implementation of storage applications in the Dutch power grid. This is filtered from the initial concourse, which is available on request, as well as all the substantiating statements referred to in the Q-Set.
The last column represents Deliverable 3. It mentions how the individual sources perceive the various external forces, either as opportunity (pro) or as barrier (con).

Table 5 - Source Reference for the Literature Review

This table describes all sources referred to in the Q- Sets including the added value of each individual source for this thesis.

On Request:

1. The Complete Concourse – All statements filtered from literature. Interviews and Discussions on storage applications
2. An extensive list of statements substantiating Q – Sort 1 as referred to in Table 3.
3. An extensive list of statements substantiating Q – Sort 2 as referred to in Table 4.

Important aspects of storage
The following parameters are often used to assess the capabilities of storage applications:

Maturity of Technology - This is the level of experience with the practical application of the technology or the level of scientific substantiation for its capacity;
Safety - The level in which the possible security hazards applicable to the technology can be controlled and limited;
Reliability - The level of effective functioning of the technology without mistakes;
Physical facilities – The physical parameters such as the weight and area needed, but also the requirements with regard to heat, and so on;
Geographical requirements – The requirements with regard to the lay-out of the physical environment in which the technology is used;
Reaction Time – The time needed for the storage capacity to react to the energy and power requirement applicable to the system service for which it is designed. The reaction time depends on the rate of:
Power absorption – The reaction time to assimilate (surplus of) electricity and;
Power release – The reaction time to deliver power to the grid in times of shortage;
Costs[1] – The total lifetime costs of a system, excluding the financing costs.
Energy storage capacity – The amount of energy a storage system can hold.
Energy density – The amount of energy per weigh of volume unit.
Rated power – The power, or amount of energy per second, the storage capacity can release or absorb continuously during the (dis)charge time.
Power Density - The amount of energy per second release per weight or volume unit of the storage application.
Capital Expenses or Investment Costs – The initial investment needed to build the system, both to reach the required energy and the required power capacity.
Operational Expenses – The costs associated to the maintenance for the proper functioning of the system.
Lifetime – The amount of time or numbers of charge/discharge cycles during the system is expected to function to the applicable requirements. The cycle lifecycle is given in relation to a depth of discharge, which is the ratio of energy (dis)charged compared to its maximum capacity.
Efficiency (round-trip) – The loss of energy when converting and re-converting from and to electricity, the ratio between power out and power in.
The marginal costs – The costs of storing and reconverting a unit of electricity once a system is built.
The Levelized Costs of Energy (LCOE) – The average costs of a unit of energy or power demand calculated over the full lifetime of the system.
(Dis)charge time – This is the time the technology can provide or absorb energy at the required power.
Self-discharge – The amount of energy dissipating in unloaded condition.

The Storage Options and their Parameters
The classification of storage technologies can roughly be subdivided in the following categories:

Mechanical Storage
Mechanical options include the storage of energy as potential or kinetic energy. The first consist of both hydropower and Compressed Air storage, while the second involves the utilization of flywheels.

Pumped Hydro Storage (PHS)
The system consists of multiple reservoirs located at different elevations. Electricity is stored as potential energy by pumping water to a higher reservoir and discharged in a turbine for regeneration.
The system is both technologically and commercially mature, it has high energy and power capacity and a long-life time, both in time and cycles. PHS is considered the most viable technology for large-scale storage of energy. Furthermore, the system has a good reaction time and high round-trip efficiency. PHS is used for energy management.
Although its technological capacity would enable its usage for load-levelling, its physical and environmental requirements limit its usage to vast, mountainous terrains. As such, the transmission of electricity back and forth makes PHS unusable for load management.

[1] The costs are correcte for inflation. Possible reductions due to learning effects and economies of scale are however to taken into account.

From the point of view of economics, PHS is cheap in operations, but requires high investments and considerable financing costs due to its building time. As such, the interest rates have a high influence on the *LCOE*. (Dell & Rand, 2001; Evans et al., 2012; Kyriakopoulos & Arabatzis, 2016)

Compressed Air Energy Storage (CAES)

Like PHS, Compressed Air Energy Storage converts electricity in potential. Electrical energy is used to compress air into caverns via compressors and released via generators. Despite the necessity to use inefficient compressors, the energy economics are good due to the high ESOI of the system. CAES can operate at higher rated power, but during shorter periods than PHS-systems. The system is also limited to suitable areas. CAES as low commercial viability due to the high investment costs and the long construction time, making the interest rates influential for the *LCOE* despite having the lowest marginal cost of storage (Evans et al., 2012; Kyriakopoulos & Arabatzis, 2016)

Flywheels

A flywheel converts electricity in kinetic energy by speeding up a wheel. Electricity is recovered via the use of a generator, slowing the wheel down. The energy stored is proportional to the mass and to the square of the angular velocity, requiring high tensile strength and the avoidance of friction.
Flywheels are capable of generating high power with fast reaction times, albeit with a low energy capacity. This makes them useful for small scale power quality management, but not for energy management. (Evans et al., 2012; Kyriakopoulos & Arabatzis, 2016)

Batteries

Battery systems can be classified in five groups of which the Lead-Acid and Lithium-Ion are currently the most often used. The ESOI of batteries is low compared to mechanical and chemical storage systems, but it has the highest round-trip efficiency of all storage systems, reaching up to 95%.
As the system requires no start-up time, the system has been widely used as *UPS*, or Uninterruptible Power Supply, by consumers and utilities. As their energy and power capacity increases, they are increasingly considered to act as spinning reserve for generators, for power quality, load and small-scale energy management.
They however have low cycle lifetime. Depending on the environmental conditions, the cycle lifetime can be as low as 500 cycles. Has such, their operational lifetime is often shorter than their payback period, leading to high costs per unit of power. Although they are not economically efficient, their purchase costs are low due to low interest rates and economy of scales, making them commercially affordable.
(Barnhart et al., 2013; Dell & Rand, 2001; Evans et al., 2012)

RHFC

A *Regenerative Hydrogen Fuel Cell* consists of multiple systems, which can be operated individually from one another. Electricity is converted to hydrogen via an electrolyser and subsequently pressurized and purified for storage or transportation. A fuel cell is used to regenerate electricity. alternatively, the use of hydrogen in conventional combustion engines is increasingly researched, as this would enable heavy-duty utilization currently unfeasible for electrical energy, such as Deepsea shipping.
The creation of an energy carrier is considered the biggest advantage of *RHFC* systems, as it enables its usage in multiple sectors and creates flexibility for transport. The necessity to use multiple systems does however lead to high investment costs and reduces the round-trip efficiency. Despite this, the system does reach higher full chain efficiency than both fossil energy and other storage applications, apart from the mechanical options.
RHFC systems can be configured independently and are therefore useable in all system services, without geological requirements. The usage of tanks in lieu of caverns does however reduce their energy efficiency. Furthermore, from economical point of view, the system is limited by the efficiency and lifetime of the fuel cell. (Dell & Rand, 2001; Frois, 2017; Hovsapian, 2017; Mohanpurkar et al., 2017; Oldenbroek et al., 2017; Pellow et al., 2015)

A final category is Electrical Storage, which involves the usage of super capacitators and magnetic energy storage. These applications actually store electrical energy. The first by storing electricity in an electric field between two electrodes and the second within a magnetic field. Although both technologies are anticipated to have large benefits in grid applications, they are not discussed further in this thesis as they are still very experimental.

Table 2 - An overview of Key-Parameters of Storage Applications

System	Type	Efficiency	ESOI	Energy Capacity	Rated Power	Reaction Time	Discharge T	Energy Density	Power Density	Lifetime		Capital Costs		Operational Costs	Notes	Sources
		(%)		MWh	MW			(WH/kg)	(W/kg)	Years	Cycle	Power (€/kW)	Energy (€/kWh)	(€/kW)		
Lithium-Ion Battery	Chemical / Direct	70-95	35	4 - 24	0.1 - 10	Immediate / Spinning Reserve	Minutes to Hours	75 - 200	200 - 300	5-15	up tp 6000	1000 - 2000	1000 - 2000		1) In average Grid applications, 6000 cycles will last 3.2 years. 2) Self-Discharge of 8% per month	L20, L24, L26, L29, L54, L55, L56
Lead-Acid Battery	Chemical / Direct	70 - 90		3 - 48	1	Immediate / Spinning Reserve	Seconds to Hours	30 - 50		3-12	100 - 2000	300	190 - 400	10	1) Self-Discharge of 8% per month	L20, L26, L29
Flow-Batteries	Chemical / Direct	80	14	4-40	1-10	Immediate / Spinning Reserve	Hours	25	80 - 150		>16.000	630	3200	28		L20, L24, L26, L29
Electrolyzers	Electricity to Hydrogen	70 - 97				30 seconds				100.000 running hours		100 - 3476		10 - 60	1) Overall Energy Efficiency of 0.83 2) Reaction time reduced to <10 seconds using *FEC* .	L8, L20, L24, L26, L47, L55, L56
Fuel Cell	Hydrogen to Electricity	50 - 60			0 - 50	1sec	1sec to 24h	800 - 10.000		5-15	>10000	5500 - 5700			1) Reaction time reduced to immediate when kept running at low loads.	L4, L8, L11, L20, L26, L47, L54, L55
Regenerative Hydrogen Fuel Cell (RHFC, including pressurizing)	Electro-Chemical / Indirect	20 - 50	(4) 59 - 110				up to 24 hours per cell			10.000 running hours		450 - 1200 / 6700 Under / Above ground			1) Overall Energy Efficiency = 0.3 2) Full Chain Eff. = 40-45%, at **42€/kWh** 3) Fossil Full Chain eff. = 40-42%, at **0.09€/kWh**	L4, L8, L24, L47, L53, L54, L55, L56
Pumped Hydroelectricity Storage (PHS)	Mechanical / Direct	65-85	830		100 - 5000	10 seconds	Days to Weeks	0.5 - 1.5		40 - 60	>15.000	12 - 605	101 - 2000	3		L20, L24, L26, L55, L56
Compressed Air Energy Storage	Mechanical / Direct	40 - 89	1100	250	3 - 400	10 seconds	Hours	10 - 60		20 - 60	>15.000	800 - 2050	50 - 100	6	1) **Marginal Cost of storage: 0.03 - 0.05€/kWh** 2) Small Self-Discharge	L20, L24, L26, L27, L55, L56
Flywheel	Mechanical / Direct	93 - 95			0.25	Immediate	Miliseconds to 15 minutes	10 - 50	1000 - 5000	15	>100.000	350	300 - 5000		1) 100% Self-Discharge	L20, L24, L26

Source references: https://nl.global-rates.com/economische-statistieken/inflatie/consumentenprijzen/cpi/verenigde-staten.aspx (20-09-2019), Euro https://nl.global-rates.com/economische-statistieken/inflatie/consumentenprijzen/hicp/eurozone.aspx (20-09-2019), https://www.wisselkoers.nl/dollar-euro (20-09-2019)

(Barnhart et al., 2013; Evans et al., 2012; Frois, 2017; González et al., 2004; Hall & Bain, 2008; Haspels, 2018; Hovsapian, 2017; Kyriakopoulos & Arabatzis, 2016; Oldenbroek et al., 2017;

Table 3 - Q - Set 1: The Anticipated Roles and Utilities of Electrical Storage Applications

Q-Sort 1: Wat is, volgens u, de noodzaak voor het implementeren van opslag en conversie applicaties in het elektriciteitsnetwerk? De noodzaak om:			
#	**Statement**	**Source**	**Page / Slidenumber**
1	Het in tijd scheiden van productie en gebruik van elektriciteit.	Lund&Münster, 2003 (L2) Türkay&Telli, 2011 (L8) van Wijk, 2018 (L10) Vasquez et al., 2012 (L25) Dunn, Kamath & Tarascon, 2011 (L27) Gottwald et al., 2011 (L50) Mohanpurkar et al., 2017 (L57)	71 1941 3 3881, 3888 929 8172
2	Importeren van elders geproduceerde 'elektrische' energie.	Dell&Rand, 2001 (L1) van Oldenbroek et al., 2017 (L4) van Wijk, 2018 (L10) van de Poll, 2019 (L51) Boeters, 2018, (L15) de Boer et al., 2014 (L28) Hall & Bain, 2008 (L29) van der Meijden, 2017 (L38) Mackay, 2013 (L52)	6 23-24 2 2, 3, 4, 5 2 362 4352 20 - 21 4, 7
3	De substitutie van fossiele brandstoffen middels conversie.	Hoogland, 2017 (L9) van Wijk, 2018 (L10) van Wijk, 2014 (L11) Weeda & Gigler, 2018 (L14)	62-64 1 42 4, 5
4	Stabiliseren van de variabele output van hernieuwbare elektriciteit.	Dell&Rand, 2001 (L1) Hoogland, 2017 (L9) Koç, 2015 (L12) van de Poll, 2019, (L51) Kyriakopoulos&Arabatzis, 2016 (L20) Vasquez et al., 2012 (L25) Mohanpurkar et al., 2017 (L57) Hovsapian, 2017 (L53)	2 12, 13 4, 97-103 5 1045 3881, 3890, 3892 3, 7, 11, 15 22
5	Verhogen van de efficiëntie van fossiele productie.	Dell&Rand, 2001 (L1) van Wijk, 2014 Vasquez et al., 2012 (L25) Evans, Strezov & Evans, 2012 (L26) Dunn, Kamath & Tarascon, 2011 (L27) de Boer et al., 2014 (L28) Haspels, 2018 (L47)	7 42, 68 3888 4142 929 367 4
6	De grotere druk op het netwerk aan kunnen.	Lund&Münster, 2003 (L2) Hoogland, 2017 (L9) Koç, 2015 (L12) van de Poll, 2019 (L51) Johansson & Turkenburg, 2004 (L18) vd Berg, 2019 (L49) Mohanpurkar et al., 2017 (L57)	71 6 3, 4, 97-103 2 21-23 - 3

Q-Sort 1: Wat is, volgens u, de noodzaak voor het implementeren van opslag en conversie applicaties in het elektriciteitsnetwerk? De noodzaak om:			
#	**Statement**	**Source**	**Page / Slidenumber**
7	Integratie van energienetwerken, zoals gas en elektriciteit.	van Oldenbroek et Al., 2017, (L4) Hoogland, 2017 (L9) Weeda & Gigler, 2018 (L14) NA, 2015 (L17) van der Meijden, 2017 (L38) Wiersma, 2017 (L39) Haspels, 2018 (L47)	2&3 12&13 19, 55 8, 12 19 4, 7 3
8	Integratie van de elektriciteitssector met andere sectoren (bijvoorbeeld de transportsector).	Dell&Rand, 2001 (L1) van Oldenbroek et al., 2017 (L4) van Wijk, 2018 (L10) Weeda & Gigler, 2018 (L14) NA, 2015 (L17) Kyriakopoulos&Arabatzis, 2016 (L20) Kelly et al., 2009 (L22) van der Meijden, 2017 (L38) Wiersma, 2017 (L39) Hovsapian, 2017 (L53)	13 2 1-2 4, 17 35 1061 893 16 4, 7 3
9	Behouden van huidig betrouwbaarheid om veiligheid te garanderen.	Dell&Rand, 2001 (L1) Lund&Münster, 2003 (L3) Koç, 2015 (L12) Gonzalez et al., 2004 (L23) Vasquez et al., 2012 (L25) de Boer et al., 2014 (L28) Diekman, 2017 (L32) N.A., 2018 (L33) Gottwald et al., 2011 (L50)	6 71 1- 4, 97-103 488 3881 362 - - 8163
10	Behouden van huidig betrouwbaarheid voor de economie.	Dell&Rand, 2001 (L1) Koç, 2015 (L12) van de Poll, 2019 (L51) Johansson & Turkenburg, 2004 (L18) Kelly et al., 2009 (L22) Dunn, Kamath & Tarascon, 2011 (L27) Diekman, 2017 (L32) van Heerde, 2018 (L34)	2 3, 97-103 5 21-23 892 928 - -
11	Behouden van huidig betrouwbaarheid om levensstandaard te handhaven.	Dell&Rand, 2001 (L1) Koç, 2015 (L12)	16 97-103
12	Beperken van grote schommelingen van elektriciteitsprijzen.	Jorgensen and Ropenus, 2008 (L24) van Swaay, 2018 (L45)	5335 18
13	Verkleinen van energieafhankelijkheid van andere landen.	Johansson & Turkenburg, 2004 (L18) van Wijk, 2018 (L40) Mackay, 2013 (L52)	5 - 4, 7

Q-Sort 1: Wat is, volgens u, de noodzaak voor het implementeren van opslag en conversie applicaties in het elektriciteitsnetwerk? De noodzaak om:			
#	**Statement**	**Source**	**Page / Slidenumber**
14	Het uitvoeren van *Power Quality Management.*	Dell&Rand, 2001 (L1) Koç, 2015 (L12) Vasquez et al., 2012 (L25) Evans, Strezov & Evans, 2012 (L26) Hall & Bain, 2008 (L29) N.A., 2018 (L33) Dunn, Kamath & Tarascon, 2011 (L27) Mohanpurkar et al., 2017 (L57) Hovsapian, 2017 (L53) Frois, 2017 (L54)	6 4 3881, 3890 4146 4352 - 934 15 14, 19 8
15	Het uitvoeren van *Load Management.*	Dell&Rand, 2001 (L1) Lund&Münster, 2003 (L2) van Oldenbroek et al., 2017 (L4) Koç, 2015 (L12) van de Poll, 2019 (L51) Vasquez et al., 2012 (L25) Evans, Strezov & Evans, 2012 (L26) Grottwalt et al., 2011 (L50) Dunn, Kamath & Tarascon, 2011 (L27) Mohanpurkar et al., 2017 (L57) Hovsapian, 2017 (L53)	6 68 3 3,4 2 3881, 3889 4146 8163 928 15 3
16	Het uitvoeren van *Energy Management.*	Dell&Rand, 2001 (L1) van Oldenbroek et al., 2017 (L4) van Wijk, 2018 Johansson & Turkenburg, 2004 (L18) Evans, Strezov & Evans, 2012 (L26) Dunn, Kamath & Tarascon, 2011 (L27) van der Meijden, 2017 (L38) Grottwalt et al., 2011 (L50) Mackay, 2013 (L52)	6 3 1-2 21-23 4146 934 16 8163 6

Table 4 - Q - Sort 2: The Perceived Barriers and Opportunities with regard to the Implementation of Storage Applications

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	**Statement**	**Source**	**Page / Slidenumber**	**Pro or Con**
		PESTLE - Theme: Politics		
1	De politieke aandacht voor de betrouwbaarheid van het netwerk.	Dell&Rand, 2001 (L1) Verbong&Geels, 2002 (L5) Koç, 2015 (L12)	5 1035 97-103	Con Con Con
2	De politieke lange-termijn visie m.b.t. het netwerk.	Verbong&Geels, 2002 (L5) Koç, 2015 (L12) Johansson & Turkenburg, 2004 (L18) Kern and Smith, 2008 (L19) Diekman, 2017 (L32) vd Berg, 2019 (L49)	1025, 1031, 1035 97-103 21-23 4101 - -	Con Con Con Con Con Con
3	De politieke aandacht m.b.t. verduurzaming van elektriciteitssector.	Verbong&Geels, 2002 (L5) Boeters, 2018, (L15) Johansson & Turkenburg, 2004 (L18) vd Berg, 2019 (L49)	1035 4 21 - 23 -	Con Con Pro Con
4	De helderheid van de politieke visie t.o.v. verduurzaming.	Verbong&Geels, 2002 (L5) Hoogland, 2017 (L9) NA, 2015 (L17) Johansson & Turkenburg, 2004 (L18) Kern & Smith, 2008 (L19) van Dril, 2018 (L41) van Swaay, 2018 (L45)	1035 54 27 21-23 4098 20 12	Con Con Con Con Con Con Con
5	De politieke erkenning van balanceerproblemen.	Verbong&Geels, 2002 (L5) van de Poll, 2019 (L51)	1031 5	Con Con
6	De politieke kennis m.b.t. de mogelijkheden van opslag.	Hoogland, 2017 (L9)	12-13, 54	Con

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	**Statement**	**Source**	**Page / Slidenumber**	**Pro or Con**
		PESTLE - Theme: Economy		
7	De rentabiliteit van balanceren via opslag t.o.v. fossiele productie.	Lund&Münster, 2003 (L2)	72	Pro
		van Oldenbroek et al., 2017 (L4)	23-24	Pro
		Türkay&Telli, 2011 (L8)	1942	Pro
		Hall & Bain, 2008 (L29)	4352	Pro
		Haspels, 2018 (L47)	6	Con
		Mohanpurkar et al., 2017 (L57)	2,3	Pro
		Hovsapian, 2017 (L53)	14	Pro
		Frois, 2017 (L54)	15	Pro
		Pellow, 2015 (L55)	12	Pro
8	De aanwezigheid van investeringskapitaal.	Dell&Rand, 2001 (L1)	5	Con
		Hoogland, 2017 (L9)	12	Both
		Schwartz, 2018 (L13)	1	Con
		Johansson & Turkenburg, 2004 (L18)	15, 18	Pro&Con
		van Dril, 2018 (L41)	20	Both
		van Swaay, 2018 (L45)	12, 15	Both
9	De investeringskosten van opslag.	van der Stelt et al., 2018 (L3)	276	Con
		Türkay&Telli, 2011 (L8)	1942	Con
		Boeters, 2018, (L15)	2	Pro
		Johansson & Turkenburg, 2004 (L18)	15, 21-23	Con
		Jorgensen and Ropenus, 2008 (L24)	5340	Con
		de Boer et al., 2014 (L28)	361	Con
		van Dril, 2018 (L41)	3, 6	Both
		Haspels, 2018 (L47)	6	Con
		Gottwald et al., 2011 (L50)	8172	Con
		van de Poll, 2019, (L51)	3 - 5	Con
		Pellow, 2015 (L55)	8	Both
10	De financieringskosten van opslag.	Johansson & Turkenburg, 2004 (L18)	15, 18	Con
		Kern and Smith, 2008 (L19)	4101	Con
		Kyriakopoulos and Arabatzis, 2016 (L20)	1064	Con
		van Swaay, 2018 (L45)	12, 15	Con

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	Statement	Source	Page / Slidenumber	Pro or Con
PESTLE - Theme: Economy				
11	De operationele kosten van opslag.	Türkay&Telli, 2011 (L8)	1942	Pro
		Weeda & Gigler, 2018 (L14)	5, 17	Con
		Jorgensen and Ropenus, 2008 (L24)	5340	Pro
		Pellow, 2015 (L55)	1	Con
12	De overall kosten per kWh van opgeslagen elektriciteit.	van der Stelt et al., 2018 (L3)	276	Con
		van Oldenbroek et al., 2017 (L4)	23	Pro
		N.A., 2018 (L7)	2	Pro
		Weeda & Gigler, 2018 (L14)	17, 32, 53	Con
		Boeters, 2018, (L15)	1, 2	Pro
		He et al., 2011 (L21)	1575	Pro
		Dunn, Kamath & Tarascon, 2011 (L27)	929	Con
		van Wijk, 2018 (L40)	5	Pro
		de Wit, 2018 (L42)	-	Both
		Gottwald et al., 2011 (L50)	8172	Con
		Frois, 2017 (L54)	10	Pro
		Pellow, 2015 (L55)	12	Pro

PESTLE - Theme: Social				
13	De maatschappelijke aandacht m.b.t. de betrouwbaarheid van het netwerk.	Koç, 2015 (L12)	4	Con
14	De maatschappelijke erkenning van balanceerproblemen.	Barnhart et al., 2013 (L56)	2808	Con
15	De maatschappelijke steun m.b.t. verduurzaming van elektriciteitssector.	Dell&Rand, 2001 (L1)	5	Con
		Verbong&Geels, 2002 (L5)	1035	Con
		Johansson & Turkenburg, 2004 (L18)	18	Con
		van Dril, 2018 (L41)	18	Both
		vd Poll, 2019 (L51)	4	Con
16	De maatschappelijke acceptatie van hogere elektriciteitsprijzen.	Dell&Rand, 2001 (L1)	5-6	Con
		Gottwald et al., 2011 (L50)	8172	Con

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	**Statement**	**Source**	**Page / Slidenumber**	**Pro or Con**
	PESTLE - Theme: Social			
17	De maatschappelijke kennis en vertrouwen in opslag.	NA, 2015 (L17) van Wijk, 2018 (L40)	2 26	Con Con
18	De maatschappelijke erkenning van de voordelen van duurzame elektriciteit.	Dell&Rand, 2001 (L1)	2	Pro
	PESTLE - Theme: Technology			
19	De technologische mogelijkheden van balanceren d.m.v. opslag.	van Oldenbroek et al., 2017, L4 Johansson & Turkenburg, 2004 (L18) Vasquez et al., 2012 (L25) Dunn, Kamath & Tarascon, 2011 (L27) Boer et al., 2014 (L28) Gottwald et al., 2011 (L50) Mohanpurkar et al., 2017 (L57) Mackay, 2013 (L52) Hovsapian, 2017 (L53) Pellow, 2015 (L55)	24 21 - 23 3881, 3885, 3888 929 361 872 15 9 17-19 2	Pro Pro Both Both Pro Pro Pro Both Both Pro
20	De technologische mogelijkheid m.b.t. substitutie van fossiele brandstoffen.	Nelson et al., 2009 (L6) M. Van der Meijden (L38)	898 16	Pro Pro
21	De praktische en theoretische kennis van opslag in Nederland.	Weeda & Gigler, 2018 (L14)	5	Pro
22	De aanwezigheid van gekwalificeerd personeel in Nederland.	Weeda & Gigler, 2018 (L14) van Dril, 2018 (L41)	63 13	Pro Pro
23	De voorraad aan grondstoffen/materialen voor opslag.	Evans, Strezov & Evans, 2012 (L26) Hall & Bain, 2008 (L29)	4145 4352	Con Con
24	Alternatieven voor verduurzamen zoals *Carbon Capture and Storage.*	Jorgensen and Ropenus, 2008 (L24) van Swaay, 2018 (L45) Gottwald et al., 2011 (L50)	5342 - 5343 12 8163	Con - Both

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	**Statement**	**Source**	**Page / Slidenumber**	**Pro or Con**
		PESTLE - Theme: Legislation		
25	De wettelijke scheiding tussen productie, handel en distributie van elektriciteit.	Hoogland, 2017 (L9)	1&19	Con
		Boeters, 2018, (L15)	4	Con
		Heeger, 2007 (L37)	148 - 149	Con
26	De regelgeving t.o.v. implementatie van opslag.	Hoogland, 2017 (L9)	19, 54	Con
		Johansson & Turkenburg, 2004 (L18)	21 - 23	Con
		He et al., 2011 (L21)	1584	Con
		Heinen, 2018 (L44)	Discussion	Con
27	Het anti-discriminatoir karakter van de regelgeving m.b.t. Elektriciteitsproductie.	Hoogland, 2017 (L9)	19	Con
		He et al., 2011 (L21)	1576	Con
		vd Berg, 2019 (L49)	2	Con
28	De beleidsmatige ondubbelzinnigheid van de term ‘energieneutraal’.	van Dril, 2018 (L41)	18	Con
		Heinen, 2018 (L44)	Discussion	Con
29	De wet maakt opslag mogelijk.	Hoogland, 2017 (L9)	12	Con
		Boeters, 2018, (L15)	4	Con
		NA, 2015 (L17)	27	Con
		Diekman, 2017 (L32)	-	Con
30	De regelingen m.b.t. subsidies voor opslag.	Johansson & Turkenburg, 2004 (L18)	21 - 23	Con
		Kern & Smith, 2008 (L19)	4098	Con
		Jorgensen and Ropenus, 2008 (L24)	5342 - 5343	Con
		van Dril, 2018 (L41)	18	Both
		Mohanpurkar et al., 2017 (L57)	15	Con

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	**Statement**	**Source**	**Page / Slidenumber**	**Pro or Con**
	PESTLE - Theme: (business) Environment			
31	De integratie van milieuschade in de elektriciteitsprijzen.	Koç, 2015 (L12)	1, 2, 3	Con
		Schwartz, 2018 (L13)	1	Con
		Johansson & Turkenburg, 2004 (L18)	21 - 23	Con
		Gonzalez, McKeogh and Gallachoir, 2004 (L23)	488	Con
32	De aanwezigheid van geografische kenmerken benodigd voor opslag.	Dell&Rand, 2001 (L1)	3	Con
		van Wijk, 2018 (L10)	1-2, 4	Both
		van de Poll, 2019, (L51)	5	Con
		Evans, Strezov & Evans, 2012 (L26)	4141 - 4142	Con
		van Wijk, 2018 (L40)	16	Pro
		Mackay, 2013 (L52)	6	Con
33	De decentrale ligging van hernieuwbare elektriciteitsproductie bronnen.	van der Stelt et al., 2018 (L3)	266	Pro
		Verbong&Geels, 2002 (L5)	1030	Pro
		van de Poll, 2019 (L51)	3	Pro
		Boeters, 2018, (L15)	2	Pro
		Bongaerts, 2018 (L46)	2	Pro
		Gottwald et al., 2011 (L50)	8163	Pro
		Mohanpurkar et al., 2017 (L57)	3	Pro
34	De scheiding tussen publieke, semipublieke en commerciële verantwoordelijkheden in de elektriciteitssector.	Verbong&Geels, 2002 (L5)	1029-1030	Con
		van de Poll, 2019, (L51)	5	Con
		Kern and Smith, 2008 (L19)	4094 - 4095	Con
		Gonzalez, McKeogh and Gallachoir, 2004 (L23)	472	Con
		Heeger, 2007 (L37)	147 - 149	Con
		Heinen, 2018 (L44)	Discussion	Con
		Bongaerts, 2018 (L46)	Discussion	Con

Q-Sort 2: Wat zijn, volgens u, op dit moment kansen voor de implementatie van opslag en conversie applicaties in het elektriciteitsnetwerk?				
#	Statement	Source	Page / Slidenumber	Pro or Con
PESTLE - Theme: (business) Environment				
35	De 'level playing field' tussen hernieuwbare en fossiele productie	Verbong&Geels, 2002 (L5)	1026	Con
		Hoogland, 2017 (L9)	7	Con
		van Wijk, 2018 (L10)	1	Con
		van Wijk & Verhoef, 2014	40	Con
		van de Poll, 2019, (L51)	3	Con
		Weeda & Gigler, 2018 (L14)	78	Con
		Johansson & Turkenburg, 2004 (L18)	21 - 23	Con
		Kern and Smith, 2008 (L19)	4101	Con
		Gonzalez, McKeogh and Gallachoir, 2004 (L23)	488	Con
36	De huidige beschikbaarheid en prijzen van fossiele brandstoffen	Nelson et al., 2009 (L6)	892	Pro
		Hoogland, 2017 (L9)	7	Con
		Kelly et al., 2009 (L22)	892	Pro

Appendix 3.3 – Bibliography for the Literature Review

A lot of sources are used in order to compile the concourses for the two concourses as well as executing the literature review. On the following pages is a complete overview of the sources used.

The way these texts were selected is described in the report. The sources include a selection of academic papers, newspaper articles, articles in professional journals, consultancy reports written on behalf of the Dutch government, books from the academic library of the Delft university of Technology and last but not least, descriptions of attended presentations and (un)structured discussions and interviews with affiliated experts.

It includes a résumé of the conclusion drawn by the authors and the objectives with which the piece was written and, if applicable, the research described was undertaken. Furthermore, it contains the added value of each text for this research and thus the reason for which it was included in the reference list of the concourses.
As such, it contains sources on electricity/energy management, storage applications, energy management and so on. Each source is given a unique code, starting with the letter L. One can use this code to correlate any statement, reference, and so on in the research, Concourses and report to the correct source.

A more extensive description and epitome of the sources can be obtained digitally.

Table 5 - Source Reference for the Literature Review

Academic Papers				
Code	**Authors** **Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L1	R.M. Dell D.A.J. Rand 2001	Energy storage — a key technology for global energy sustainability	The paper discusses an overview of the global energy usage up to 2020 with emphasis on the incorporation of renewable energy. It discusses the use of multiple forms, including their pros and cons, of electricity storage to enable the efficient use of renewable production.	The expected growth of world energy usage to 2021 is 40%. Energy is highly valued and its consumption is inelastic. Renewable energy production prediction is 6.5 - 11 out of 20.0 PWh in 2020. Wind power is erratic and therefor unreliable. There is need for storing energy generated by renewables. Pumped-Hydro is best way to store large quantities of energy. Flywheels and batteries can store small amounts of energy. Flywheels are complimentary to batteries. Fuel cells have promising future for both stationary and moving applications.
L2	H. Lund E. Münster September 2003	Management of surplus electricity-production from a fluctuating renewable-energy source	The paper discusses and analyses different national strategies for solving the problem of (Critical) Surplus of Electricity Production. It uses the case of Denmark as an case example. It provides current accepted alternatives for the implementation of storage to prevent overloading of the power grid.	The costs of avoiding Critical Surplus of Electricity Production are much lower than investing in high-voltage transmission lines. The best strategy to avoid Critical Surplus of Electricity Production is to invest in flexibility in the energy system (storage). Investing in flexibility is the best strategy,
L3	S. vd Stelt A.S. Tarek W. v Sark January 2018	Techno-economic analysis of household and community energy storage for residential consumers with smart appliances	The paper assesses the technical and economic feasibility of both Household Energy Storage and Community Energy Storage using a mathematical model simulating several battery types.	Under current initial investment costs of Energy Storage Systems per kWh, both household and community storage are economically infeasible. .

Academic Papers				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L4	V. Oldenbroek L.A. Verhoef A.J.M. v Wijk March 2017	Fuel cell electric vehicle as a power plant: Fully renewable integrated transport and energy system design and analysis for smart city areas	The paper answers the question whether for city areas, solar and wind electricity coupled to fuel cell electric cars as energy generators and distributors and hydrogen as energy carrier can provide a 100% renewable, reliable and cost effective energy system for power, heat and transport. It thus provides a (technological) feasibility study to indirect storage and the integration of the energy and transportation sector.	Fuel cell electric cars using hydrogen as energy carrier can provide a 100% renewable, reliable and cost effective energy system for power, heat and transport. Additional hydrogen can be produced at distant wind and solar parks and transported. The reliability and the balancing of electricity is guaranteed by the cars with fuel cells. The system is economically feasible.
L5	G. Verbong F. Geels February 2002	The on-going energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004)	The paper identifies important lessons from a long-term analysis of the Dutch electricity system using a socio-technical and multi-level theory. It provides insight in the role of policy into steering sustainable development and the consequences of regulations for the risks of investments.	Although Environmental concerns do receive in the energy transition, in terms of guiding principles, they rank below the issues of low cost, reliability and diversification. Furthermore, most renewable innovations have run into trouble in social embedding.
L6	K. Nelson T. Gibson J. Spearot D. Ouwerkerk December 2009	Development of a renewable hydrogen economy: Optimization of existing technologies	The paper describes methods for optimizing the conversion of electricity generated from household solar panels into useful transportation fuel (stored energy in batteries or hydrogen). It thus explains technological and economical feasibility of indirect storage and the integration of two sectors.	An average rooftop (47m2) with solar arrays can generate enough electricity (30kWh) and/or hydrogen (0.5kg) for the daily use of a car for an average household.

Academic Papers				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L8	B. E. Türkay A. Y. Telli July 2011	Economic analysis of standalone and grid connected hybrid energy systems.	The paper describes the feasibility of using an hybrid system of solar and wind energy and hydrogen as storage medium to supply energy to the Electronics faculty of the university of Istanbul. It thus compares a stand-alone system of solar panels connected to the grid, with one in which storage is integrated. It therefor provides insight in the additional value of storage, both technological and economical.	(1942) Solar and wind energy in combination with indirect storage increased the output. The costs per kWh are comparable with grid electricity, however hampered by the high initial costs. The operational costs however are low. Initial costs are expected to drop faster than conventional systems.
L18	T. Johansson W. Turkenburg March 2004	Policies for renewable energy in the European Union and its member states: an overview	In Europe, the renewable energy flows are large compared to the commercial demand. The fragmented market in Europe result in sub-optimal use of the energy due to market and system failures. This paper discusses the need and possibilities of policy instruments to reach guiding objectives and regulatory infrastructures to enable an efficient and effective energy market. This paper thus discusses the influence of policies and regulations on the energy market and innovations here in.	Concerns in Europe over energy supply, environment, economic competitiveness and regional development. Higher penetrations of renewable energy technically possible with investments in storage capacity. Significant political support for renewable energy production in the EU and impressive investments are going on. European long-term commitments are needed as drivers for innovation. Clear policy instruments and regulatory infrastructures are needed. Two major issues: uneven use of subsidies for conventional energy production and lack of incorporation of external costs in market conditions. Administrative procedures are major barriers. Lack of champion to sponsor renewable energy.

Academic Papers				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L19	F. Kern A. Smith November 2008	Restructuring energy systems for sustainability? Energy transition policy in the Netherlands	The researchers investigate a "transition management" model used in the Netherlands with the aim of restructuring the energy systems into more sustainable forms. The model aims to promote more radical, system-level innovations. The analysis is based on 27 semi-structured personal interviews, selected using the snowball approach en balanced between insiders and outsiders. This paper thus describes the role of non-technological, institutional, aspects in the integration of innovative technologies such as storage.	The Dutch approach created long-term visions by aiming for system innovation in the energy sector, as well as investigating and incorporating stakeholder involvement. However, the paper argues that the approach risks capture by the incumbent energy regime, thereby undermining the aim for radical changes.
L20	G. L. Kyriakopoulos G. Arabatzis April 2016	Electrical energy storage systems in electricity generation: Energy policies, innovative technologies, and regulatory regimes	The study conducted for this paper explores which technologies will be needed most in future energy systems, which technologies have room for improvement and which policy considerations influence the rollout and penetration of certain technologies. It thus couples policy and economy to technology in terms of feasibility.	The penetration of Renewable Energy Production necessitates more frequency control capability of power systems. The amount of Electrical Energy Storage needed in future energy systems worldwide ranges between 50 - 90 GA, taking into account the net output variation of renewable energy production. What constitutes a good technology mainly depends on the perspective of the decision maker, whereas efficiency and lifetime are less important.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L21	X. He E. Delarue W. D'haeseleer JM. Glachant March 2011	A novel business model for aggregating the values of electricity storage	Most evaluation methods of storage capacity are conceived for one specific use of the storage, often leading to the conclusion that the investment does not pay off. The research discussed in this paper proposes a new business model allowing the aggregation of multiple revenue streams of electricity storage in a systematic way via an auctioning system for the right to use a storage system. The model is demonstrated by a case study, and results show that a storage unit can achieve higher return on investment. It thus provide good comparisons between conventional usage of the power grid and the implementation of storage.	Economic viability of storage technologies is low due to the lack of a proper mechanism to capture the overall value of storage. Regulations play an important role in the development of electricity storage by providing (un)certainty for investors and by failing to recognize the value of storage for the whole system. The challenge for policymakers and regulators is to design appropriate mechanisms to coordinate the use of storage with credible signals and without bias to specific users.
L22	N. Kelly T. Gibson J. Spearot D. Ouwekerk December 2009	Development of a renewable hydrogen economy: Optimization of existing technologies	The paper challenged the increasing need for a new and greater sources of energy for future global transportation application. It discusses a research in which the output of photovoltaic cells are optimized to match the requirements of electrolysers to produce hydrogen or batteries to store chemical energy. This in order to prevent transmission losses. The paper thus discusses the technological and economical feasibility of the integration of both direct and indirect storage .to renewable energy production.	An average rooftop PV installation (47 m2), with optimized output, in Michigan produces enough hydrogen (0.5kg) or stores enough energy in batteries (30kWh) to meet the average energy demands for daily commuting. The greatest losses in solar to power output are due to the inefficient systems for home hydrogen fuelling and battery charging devices.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L23	A. Gonzalez E. McKeogh B.O. Gallachoir April 2004	The role of hydrogen in high wind energy penetration electricity systems: The Irish case	The paper studies the viability of hydrogen production via electrolysis using surplus wind power in order to deal with the constrains of wind uncontrollability and its challenges for the electricity supply system at high/increasing penetration levels of wind power. This case study in Ireland proofs both the technological and economical feasibility of indirect storage.	In Ireland, the foreseen development of wind energy will grow to amounts of electricity that the electric system will not be able to assimilate. The integration of hydrogen systems in connection with wind power generation facilitates a large penetration of wind energy. With a fair allocation of costs, the market will/should encourage the installation of wind-hydrogen systems to mitigate the high costs of grid reinforcements. Among others, the competitiveness of green hydrogen with other sources (like steam reforming) is influenced by the evolution of the fossil fuels market and the reflection of environmental costs.
L24	C. Jorgensen S. Ropenus October 2008	Production price of hydrogen from grid connected electrolysis in a power market with high wind penetration.	The fluctuations of power demand in supply caused by renewable energy production leads to significant power price fluctuations in a liberalized power market. This paper presents a study on the minimization of hydrogen production price and its dependence on estimated power price fluctuations. The price for hydrogen is derived as a function of the optimal electrolyser operation hours per year for four different wind penetration scenarios. The analysis are based on historical data from 2000 to 2007. This paper aims to back-up or correct statements taken from earlier papers combining technological possibilities of indirect storage with economical viability.	Three different studies illustrate well the uncertainty associated with the estimation of hydrogen production prices and affiliated power prices. The assumption on payment of tax and charges on power are suspected to be the greatest contributors to the differences in the production price of hydrogen derived by the studies. The estimations yielded for a minimum hydrogen price are 0.41-0.45€/Nm3 (32-35 €/GJ). This is 0.12-0.13 €/kWh, comparable to gasoline prices (0.076€/kWh). For grid balancing, electrolysis has environmentally friendly and economically more favourable technologies as competitors.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L25	Vasquez et al. December 2012	Energy Storage Systems for Transport and Grid Applications	The main objective of the paper is to introduce the subject of Energy Storage Systems and to give an updated reference to non-specialists. It presents a review of storage systems for transport and grid applications.	Energy Storage Systems are key technologies for transport and utility applications. It enables the integration of renewable generation, facilitates the emergence of smarter grids, reduces reliance on peak power plants and viable storage will enable the adoption of electric vehicles.
L26	A. Evans V. Strezov T. J. Evans August 2012	Assessment of utility energy storage options for increased renewable energy penetration	Renewable energy technologies are expected to take the leading role in the energy generation portfolio. The major constraints for increasing penetration of renewable energy sources is their availability and intermittency, which can be addressed through energy storage. The paper reviews the energy storage technologies and gives an up to date comparative summary of the energy storage options. This paper provides good insights of the technological and scientifically possibilities of storage without the constraints of regulations and policy.	Storage methods will become critical to the provision of secure and uninterrupted power. Prices and efficiencies will become more favourable, such that coupled renewable and storage energy systems will be economical. The choice of storage depends on the individual need, however it is necessary to incorporate more than one energy storage in the systems to compensate for both short and long term power interruptions.
L27	B. Dunn H. Kamath JAM. Tarascon November 2011	Electrical Energy Storage for the Grid: A Battery of Choices	The article gives a review of the battery-technologies applicable to grid management applications. The article gives a good insight in the various technological challenges of balancing and couples technological applications to each.	The Electric Power and Research Institute) study identified the following high-value opportunities for energy storage: Wholesale energy services, Integration of renewables, Power quality and reliability management, Transmission and distribution grid support and Energy management. The most important key expectations are Low installed costs, High durability and reliability, Long life and High round-trip efficiency.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L28	H.S. De Boer L. Grond H. Moll R. Benders August 2014	The application of power-to-gas, pumped hydro storage and compressed air energy storage in an electricity system at different wind power penetration levels	The paper investigates the economic and environmental consequences of the application of power-to-gas, pumped hydro storage and compressed air energy storage in an electricity system at different wind power penetration levels. This paper offers insight for so far lacking in this research: the ecological consequences of the application of storage systems.	Adding more uncontrollable renewable energy sources to the electricity system will result in an increase of the conventional power plant start-up and shutdown costs and the excess electricity production. Adding storage options to an electricity system is seen as a way to reduce these effects. The application of large scale energy storage systems resulted in a costs reducing effect on the electricity system. The highest cost reduction resulted from the application of PHS, followed by the cost reducing effects of CASE and P2G. This paper takes into account the economical benefits of storage of the full electrical system in contrast to multiple other researches that look at storage as a stand-alone system.
L29	P.J. Hall E.J. Bain December 2008	Energy-storage technologies and electricity generation	The paper investigates the employment and development of combinations of technologies to meet the demands of contemporary applications of energy storage. This paper is essential since it is the first one that considers the technological demands for developing storage, where other papers mainly focussed on the demands on policy and economy.	The evolution of the electrochemical supercapacitator and lithium-ion batteries is largely dependent on the development of optimised materials. Flow-battery development is largely concerned with safety and operability. Materials development is essential for the successful evolution of flywheel technology.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L50	S. Gottwalt W. Ketter C. Block J. Collins C. Weinhardt October 2011	Demand side management - A simulation of household behaviour under variable prices	The article discusses the efficacy and the effects of using Demand Side Management via the application of smart appliances in private households. It does so both for the effects on the households electricity usage and affiliates expenses and the effects for the utility companies from the point of view of balancing the grid. The benefit for the research is its presentation of an alternative of storage applications for balancing the grid.	From a financial point of view, households can expect low benefits from investing in smart appliances. The reduction in the price of electricity does not compensate for the initial investments needed. From an utility point of view, the household use of smart appliances makes a large share of the hourly residential load flexible which could support the balancing of the grid. It is attractive with regard to the expansion of renewable generators in Europe.
L52	D.J.C. Mackay March 2013	Could energy-intensive industries be powered by carbon-free electricity?	The article discusses the spatial consequences of switching from fossil based electricity production to carbon free generation. It first illustrates the density of energy and electricity requirements of multiple nations, focussing on the UK, versus the energy/electricity density of multiple power generation technologies. A such, it illustrates the spatial requirements needed when switching from power generation with a high energy density (fossil based) to one with a relatively low energy density (renewables). It also illustrate the necessity of providing storage facility for electricity in a system relying on renewable production. This added value for the thesis is its elaboration on the environmental impact of renewable generation in terms of living space and the affiliated technological challenges. It quantifies the scale of infrastructure required, focussing on wind and nuclear power generation.	The transition of industry to a clean low-carbon electricity supply, although technically possible with several different technologies, would have very significant infrastructure requirements.
L53	Hovsapian May 2017	Role of Electrolysers in Grid Services	The presentation provides insight in the technological feasibility of using hydrogen for balancing applications in the grid. It discusses the results of testing electrolysers in combination with fuel cells in the U.S. Power grid for balancing purposes. This is important for the thesis, as so far other sources often suggested the possibility, but real numbers were missing.	A 200 hour Testing of electrolysers coupled to the grid in combination with a FEC show that the technology enables voltage and power spinning reserve. The start-up time of the electrolyser however prevents the system to be used as frequency spinning reserve. Research is however done to use an electrolyser in steady-state mode to do so.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L54	Frois Jun2 2017	Balancing the Grid with hydrogen technologies	The presentation provides insight in the technological feasibility of using hydrogen for balancing applications in the grid. It discusses the results of testing electrolysers in combination with fuel cells in the U.S. Power grid for balancing purposes. This is important for the thesis, as so far other sources often suggested the possibility, but real numbers were missing.	The key conclusion is that Power-to-Hydrogen for balancing purposes is economically viable today.
L55	Pellow Emmott Barnhart Benson April 2015	Hydrogen or batteries for grid storage? A net energy analysis	The paper compares the technological feasibility and efficiency of grid storage via hydrogen or batteries from the point of view of energy. This enables the comparison of 'apples with apples'. This is important for the thesis as it discusses the role of direct versus indirect storage and the technological feasibility and effectivity.	From an energy perspective, it is seldom viable to use electricity storage compared to curtailment. It is cheaper to invest in additional generating capacity. However, the combination of renewable energy with storage (hybrid systems) provide all better energy returns on investments than the current utilisation of fossil fuels.
L56	Barnhart Dale Brandt Benson August 2013	The energetic implications of curtailing versus storing solar- and wind-generated electricity	The paper compares the technological feasibility and efficiency of multiple storage technologies for usage in grid applications compared to curtailment. This is done from a energetic point of view to enable the comparison of 'apples with apples'. This is important for the thesis as it discusses the role of direct versus indirect storage and the technological feasibility and affectivity.	The implementation of all storage technologies with solar power lead to energy returns on investments larger than curtailment, where with wind, this is only viable at high over generation levels. Power generators with low energy intensity such as wind turbines are, on average energetically inexpensive. Curtailing these systems is, from energetic point of view during generation, cheaper than investing in storage. Attempting to salvage energetic cheap power (e.g. wind) is wasteful from a societal perspective. Conversely, forfeiting energy that incurred at high cost through (such as photovoaic) curtailment is a waste, making the implementation of storage from an energetic point of view desirable. As such, curtailing the electricity and substitute the power needed to meet demand by fossil generation is cheaper than the environmentally better solution of harvesting energy.

Academic Papers				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L57	M. Mohanpurkar Y. Lou D. Terlip F. Dias K. Harrison J. Eichman R. Hovsapian J. Kurtz 2017	Electrolysers Enhancing Flexibility in Electric Grids	The paper discusses a case study in which electrolysers are used to provide stability to the grid in California while coupling the grid to the transportation sector. Over generation of hydrogen is used to produce hydrogen later sold in fuelling stations for hydrogen. The added value for the thesis is that in provides insight in how hydrogen technologies can be used in grid applications, which seems to be beneficial in times of over generation as long as good planning via a Front End Controller is achieved. This sounds like a good argument to let TSO's and DSO's be in charge of such systems. In terms of power quality management in times of shortages in spinning reserves applications, it seems the fuel cell (power generation) part of the RHFC is not enough to cope with the millisecond necessity.	An electrolyser in combination with a Front End Controller can enable flexibility in the grid on local level by providing local voltage and frequency support. It provides greater economic revenue than enforcing the grid.

Articles from Professional Journals				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L15	B. Boeters March 2018	Groene stroom komt als waterstof	The article shortly elaborates the visions of Ad van Wink, professor in future energy systems at TU Delft, on the future of the Dutch energy. The added value for the thesis is the emphasis on comparing molecules with electrons in contrast to other sources comparing batteries with gasses like hydrogen. It provides a new perspective and understanding of direct versus indirect storage, and possibilities of comparing the two.	One should not only look at the efficiency of a certain technology, but to its all chain. Solar and wind energy can produce with higher efficiency in other locations, and the overall efficiency of producing abroad and transport it to the Netherlands may very well be higher, and thus economically viable, than using said technology locally. It is easier to store and transport a molecule compared to an electron. There is need for new policy and more vision from the government.
L37	D.N. Heeger July 2007	Stand van zaken splitsing energiebedrijven - het groepsverbod nader beschouwd	The article aims to summarize and explain the meaning and consequences of the newly adopted law on electricity and gas in the Netherlands. It is informative for the research as it is one of the few sources that discusses the consequences of legislation on the companies in the sector. This in turn provides insight in the availability to invest in storage and, more important, the right to do so.	The new law already force the economical independence of distribution networks from generating companies and will prohibit the formation of groups between the divers links in the infrastructure. The definitive implementation will force vertical integrated companies to unbundle, and as consequence shareholders of these companies will become shareholders of independent network management companies and independent energy generation companies.

Books (Repository Delft University of Technology)				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L11	A. Van Wijk L. Verhoef 2014	Our Car as Power Plant	The book elaborates on the capacity of hydrogen fuelled cars. It compares the complete chain of the current fossil based Dutch electricity infrastructure with the chain of delivering electricity using hydrogen cars, from well to actual usage. The idea is mentioned earlier in L4, however the added value of this book is its insight in the calculations of full chain efficiencies of indirect storage.	The book does not state any hard conclusion as would be expected from an academic paper. However calculations are made and used in the statements.

Report of Hearing				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L10	Dutch house of representatives	Position Paper rondetafelgesprekken tweede EU-mobiliteitspakket	The report of the hearing describes the role of fuel-cell cars in the transportation and the (policy-oriented) salient factors for its diffusion. It provides insight in the necessities in policy from the point of view of scientists	No hard conclusions are presentenced as is expected from an academic paper. However information is used for statements.

Newspaper Articles				
Code	**Authors** **Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L13	K. Schwartz March 2018	Unilever-baas heeft spijt - of iets wat daarop lijkt	The article describes how Paul Polman, the CEO of Unilever, had to buy back 5 billion worth of stocks to please his shareholders, while he rather invested this money in the company. There is no relevance with the electricity sector, however it does emphasis a problem stated earlier in papers, the lack of will to invest or capital, often due to uncertainties and external factors.	No hard conclusions are given. However the CEO does claim that the focus on financial growth due to the power of shareholders will in the end disable economic growth. Furthermore he claims companies should focus on sustainability, which also means environment, to enable future development.
L31	N.A. August 2018	Google wil enkel nog draaien op duurzame stroom	The added value of the article is to display the view of the market environment vis-à-vis renewable electricity.	No hard conclusions can be drawn. It is however notable that one of the biggest companies in the world emphasizes its belief in the competitiveness of renewable power, while many other parties use its prices as reasons to maintain fossil based energy. Furthermore, it is notable that Google, a market company, is one of the worlds biggest investors of renewable energy, where one would expect governments or energy companies.
L32	A. Diekman September 2017	TenneT had strongest niet op orde tijdens grote storing	The added value of the paper is TenneT's point of view on the political vision, and affiliated regulations, on the power grid. It states this currently opposes maintenance and innovation to the grid which can lead to more black-outs.	A claim can be made that the current political view, and affiliated regulations, does not fully capture the necessity and challenges of grid maintenance.

Newspaper Articles				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L33	N.A. March 2018	Duitse gezant naar Balkan over 'stroomdip'	The added value of this article is the real life example of problems to the power grid, and the large area in which it can spread, described in multiple academic papers.	A claim is stated that what seems a small regional dispute in the east of Europe could very well lead to problems on the full European grid.
L34	J. Van Heerde May 2018	Nog even en de datacenters raken van stroom verstoken	The added value of this paper is a real life example of problems of congestion in the power grid, which may, in this case, lead to economical problems. The usage of local back-up buffering capacity is seen as an option to reduce the problem, however who is responsible?	A claim is made that the added value of the grid to the economy is not incorporated in the responsibilities and possibilities of power grid operators.
L49	van den Berg January 2019	Elektriciteitsnetwerken kan stroom uit lokale groene projecten niet aan	The added value of this paper is a real life example of problems of congestion in the power grid, which, in this case, leads to the incapability of both the regional and national grid operator to transport renewable electricity. This leads to curtailment of renewable in favour of fossil based electricity.	One of the claims in the article is that the power infrastructure is currently the salient factor in the energy transition. It supports claims made in academic papers stating that the combination of lack of clear vision in and durations of grid investment lead to uncertainties, and in turn in a mismatch between investments in power generation versus investments in power infrastructure.

Newspaper Articles				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L51	van de Poll, February 2019	Groene stroom genoeg in Duitsland, maar op de verkeerde plek	The article discusses the problem of energy management in terms of geography, infrastructure and societal support. The Northern and Eastern part of Germany encounters an increasing surplus of renewable electricity, while the Southern and Western part experiences increasing shortages of electricity in general. Enforcing the power grid to facilitate the exchange of electricity between the areas is very expensive. Furthermore, the development of both this infrastructure and additional renewable production sites is hampered by societal resistance based on health and aesthetic reasons.	A claim is made that the current infrastructure is designed to facilitate conventional electricity production based on coal and nuclear power. The societal resistance for the costs affiliated to alter the infrastructure to facilitate renewable production sites creates an uneven playing field between the two.

Presentation and unstructured discussions				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L38	M. Van der Meijden October 2017	North Sea Wind Power of the Future - Connecting electrons and molecules	Presentation by Professor Mart van der Meijden, working for TenneT and Delft University of Technology. The objective of the presentation was to give TenneT's (the Dutch Transmission System Operator) view on the future energy infrastructure. The added value for the research is to emphasis the view of this organisation on the implementation of indirect storage.	(Slide 19) An infrastructure based solely on electrons (electricity) is not considered realistic. TenneT assumes a ratio of 40/60 (electrons/molecules). A way to decarbonize the molecules is by replacing oil and gas by hydrogen, made from excess renewable electricity. (slide 20 and 21) Since September 13, 2017, TenneT (together with the TSO from multiple countries) investigates the creation of an energy island in sea. Advantages: Large area to spread energy and thus mitigate with intermitted production and hydrogen to create more flexibility and storage.
L39	K. Wiersma December 2017	HyStock	Presentation by Koen Wiersma, Business Developer at Gasunie (operator of natural gas infrastructure in the Netherlands) The objective of the presentation was to give Gasunie's view on the future energy infrastructure. The added value for the research is to emphasis the view of this organisation on the implementation of indirect storage.	The Gasunie, with other stakeholders, is interested in combining the infrastructure for electricity and gas. Renewable electricity can be conversed into hydrogen for storage and usage in other segments. Large-scale storage is possible in salt caverns.. This is already done in England and the USA.

Presentation and unstructured discussions				
Code	Authors Date	Title	Objective & Addition to Research	Conclusion
L40	A. Van Wijk April 2018	Groene waterstof: Het alternatief voor Gronings gas	Presentation by professor Ad van Wijk, working for the Delft University of Technology and the Green Village, on the applications of hydrogen. The added value for the thesis is that it suggests two capacities of indirect storage not discussed often in papers: the possibility of non-local production and transport and the possibility to fully substitute fossil materials for hydrogen.	Very few countries, and the Netherlands is not part of those, is capable to be fully self-sufficient for its energy. This also applies for renewable energy. Therefor, one should look at producing energy in the places best suited to do so. Batteries are possibly viable options to deal with the daily intermitted nature of renewable energy production for households, but not with the seasonal need nor for the industry. The overall efficiency (from well to usage as electricity) of hydrogen is around 40-50%, which is just as good, and often even better, than current efficiency based on fossil energy. Furthermore, the technology is relatively new, and will probably evolve, while the technology based on fossil fuels are almost fully developed.

Presentation and unstructured discussions				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L41	T. Van Dril April 2018	Economische gevolgen en maatregelen voor de energie & industrie sector	Presentation by Ton van Dril, senior scientist at ECN (Energie Onderzoekscentrum Nederland) and TNO (Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek), about the economical consequences of the Energy Transition for the Dutch Industry. It is of added value for the research as it expresses the costs of investment and emphasis these can be either considered a salient factor or a opportunity to create added economical value. This depends on the political vision and affiliated regulations of the energy transition.	Formulating concrete goals is essential to reduce the uncertainties affiliated to the transition. Otherwise, investments are impossible. Expecting market forces to carry out the transition (point of view policy-makers and society), or waiting for policy makers to set clear goals (point of view market and society), will not work. A combination of both is needed to create level playing field for competition while maintaining economical and technological efficiency. Investments needed to carry out the transition are substantial, however acceptable and affordable for the nations economy as a whole. However, it is to big for independent companies. The transition so far has positive influence on the Dutch economy.
L42	R. De Wit April 2018	De bijdrage van zon en wind en de impact op de energierekening	Presentation by Ron de Wit, Director of Energy Transition and Public Affairs at Eneco , about the financial consequences of the Energy Transition for individual citizens. The added value for the research is the claim from Eneco, a market company, that overall the usage of renewable energy is cheaper than fossil based energy when costs to the infrastructure are not taken into account. This makes integration of fossil energy easier, not cheaper.	Overall, the energy generated by wind, both on- and offshore, is cheaper than fossil based energy, if building the sites are taken into account. Greatest challenge for energy generators using renewables is to overcome seasonal changes in supply and demand.

Presentation and unstructured discussions				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L44	A. Heinen April 2018	Hedgehog application - Een revolutie in energie besparingen	Presentation, followed by informal discussion, by Arjan Heinen, founder and owner of Hedgehog applications, on the possibility of re-using 65% of the electricity currently dissipated as heat on the Dutch trains network. The added value for the research is the real life case showing the salient factor of regulations on the implementation of proven innovative technologies.	Approximately 70% of the energy generated by trains during braking dissipates as heat. This energy can be transported as electricity and stored in big batteries near train stations, reducing the loss from 70% to 5%. Approximately 70 GWh0 of energy can be re-used each year. The electricity stored is easily transferable (proof of concept in Apeldoorn) to electric busses for regional transport. However, the electricity is currently not saleable due to regulations, with emphasis on the origin of the electricity. Bus companies want to buy electricity with a 'green origin certificate' due to subsidies, however due to the 're-useable' nature of this electricity, it is not known how to provide this certificate. Furthermore, it is not determined how to label the company. Energy generator versus network manager.
L45	D.J. Van Swaay April 2018	Slimme Energietransitie	Presentation by Dirk Jan Swaay, director of Energy transition at Internationale Nederlanden Groep (ING) Bank, about the role of the banking sector in the energy transition. The added value for this research is that it illustrates both the possibilities as the current barriers of the transition from a financiers point of view.	For each investment in the transition, a viable and robust business case must be made as soon as possible. The decision whether or not to socialize the costs of investment must be made quickly in order to decide upon budgets and investments and in order to reduce uncertainties. Collaboration of the actors within the complete chain is necessary.

Presentation and unstructured discussions				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L46	M. Bongaerts April 2018	Smart Design: minder net voor meer duurzaamheid	Presentation by Martijn Bonagerts, innovation manager at Liander, about the challenges for network managers due to increasing decentralized electricity generation of renewable energy production and the economical consequences of current regulations on their connection to the network. The added value for the research is the claim that infrastructure is key in enabling the transition, but the challenges are more of regulatory nature than technological.	The costs of connecting a (renewable) production site to the grid consist on average of 10% of the initial investment costs for an owner or developer. However, the network manager, has additional expenses of about 30% of the investment costs to connect the site to the network. These cost are past on to each end-user / society as network management costs. The costs are higher than necessary since operators have to adhere to strict regulations, disabling the usage of smart design to keep costs low. Network operators should be involved in energy production projects at an early stage and regulations should be altered to enable them to optimize both the cost-benefit as technical capacity of connection to the network.
L47	J. Haspels	CO2 neutrale waterstof in flexibele gascentrales - De NUON Magnum case	Presentation by Jeffrey Haspels, Project Manager at Vattenfall, about the Magnum gas-fired power station, which aims to eventually use excess of electricity to produce ammonia and hydrogen for future re-conversion to electricity. This presentation provides a case example of using indirect storage on a big scale for balancing opportunities of the grid.	For decarbonisation, the use of hydrogen in the electricity market is considered a viable option by Vattenfall. It facilitates the integration of solar and wind power in all sectors.

Reports on Energy Transition and Storage				
Code	**Authors**	**Title**	**Objective & Addition to Research**	**Conclusion**
L9	R. Hoogland September 2017	Oversight Waterstofinitiatieven, -plannen en -toepassingen. Input voor een Routekaart Waterstof	The report was written on behalf of the Ministry of Economic Affairs and describes initiatives, plans and challenges of implementing hydrogen in the Dutch energy and industrial infrastructure. It describes real life case studies and salient factors for up scaling of pilot projects.	Most projects are still just in the idea or feasibility study phase. For market development, it seems hydrogen has the highest added value in the transportation sector, however the sales volumes are to low to become economically viable. The sales volumes are high in the industry, however hydrogen is to expensive compared to other forms of energy of raw materials to become viable in this segment. The report identifies the following needs from the parties involve A long(er) term vision from policy on the role of hydrogen in the transition, Include the use of hydrogen in the current Gas law, Legally secure the (technological) neutrality of grid connections, Subsidy for low-carbon (renewable) energy carriers, Adjustment of the Electricity law to enable the delivery of stored electricity to the power grid, Increase the allowed quota of hydrogen in the natural gas network

Reports on Energy Transition and Storage				
Code	**Authors Date**	**Title**	**Objective & Addition to Research**	**Conclusion**
L14	M. Weeda J. Gigler March 2018	Contouren van een Routekaart Waterstof	The report was written on behalf of the ministry of Economic Affairs. It acknowledges the role of hydrogen and related technologies in the on-going energy transition. It works on the report "Overzicht Waterstofinitiatieven, -plannen en - toepassingen. Input voor een Routekaart Waterstof", described in L9. This report aims to be a roadmap towards the implementation of hydrogen, and thus discusses both technological as institutional aspects.	Hydrogen seems to have the most added value for industry in the transition. Both as raw materials and for its usage as energy carrier. In order to implement hydrogen, there is need for an overall, integral , vision of the energy transition. There are over a hundred initiatives on hydrogen-usage in the Netherlands alone (L9), however the implementation of these project should start right away. Furthermore, the implementation should not be done in isolation, but in co-operation with (international) stakeholders.
L17	N.A. May 2015	Met gas naar een klimaatneutraal energiesysteem - Innovatie en Kennisagenda Gas 2016 - 2019	The report describes the role of gas in general, so it looks beyond the current focus on natural gas, in the future energy sector. It describes the current focus on electrification and the bad reputation of gas, however pleads for its necessity. Furthermore, it pleads for the integration of the energy sector to enable the flow of energy.	The report does not state hard conclusion but does however provide input for statements.

Appendix 4 – Q – Methodology

The chapter in the main report is considered to be extensive. The following information can be provided on request:

1. List of Invitations (The P – Set) including personal information
2. List of Respondents including personal information
3. Invitation Letter (Dutch)
4. Completed Questionnaires (Dutch)

Appendix 5 – Results

The chapter in the main report is considered to be extensive. The following information can be provided on request:

1. The Results of Questionnaire 1
2. The Uninterpreted Results of Q – Sort 1 and Q – Sort 2 provided by PQmethod
3. The Results of Questionnaire 3