MASTER

Aggregators and flexibility in the Dutch electricity system

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Aggregators and flexibility in the Dutch electricity system

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Master Thesis

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Abstract

The transition to an energy system, with electricity generation mainly from renewables, is changing the way we think and deal with flexibility. Issues of flexibility are becoming more apparent with the integration of more variable renewable energy (VRE) in the electricity system. VRE sources like wind and solar are not as controllable as the traditional generation of electricity with fossil fuelled generators. This results in increasing demand for flexibility and the need for new sources that can provide flexibility. The aggregator is a promising concept that can support the electricity system by unlocking and providing (new) forms of flexibility. This study looks into the way the aggregator concept is positioned in the Dutch electricity system and how this could develop in the future.

The aggregator

The aggregator is a relatively new concept that is used to describe a new actor, a formal role and an activity. The aggregator as an actor represents a new market intermediary in the electricity market. The aggregator as an actor can adopt multiple roles. The formal role of an aggregator describes the responsibilities, tasks and function of aggregators explicitly in legislation. The activity of aggregation, combining multiple customer loads or generation into a pool, is also used in describing the aggregator concept.

A typology of aggregators has been created in this thesis to conceptualize the aggregator. This typology contains a classification of six different aggregator types. Three types represent an aggregator with a combined role, the combined aggregator-supplier, the combined aggregator-BRP and the DSO as aggregator. Three other types are non-combined aggregators that solely focus on flexibility, the aggregator as service provider, the delegated/broker aggregator and the prosumer as aggregator.

Market facilitation of the aggregator

The aggregator concept in the context of the Dutch electricity market has been studied to analyse the market facilitation of the aggregator. Two types of aggregators are well supported in the Dutch electricity system, the combined aggregator-supplier and the aggregator as service provider. The combined aggregator-supplier model benefits from its similarities with the current activities of suppliers. Not actively trading electricity but offering a service makes the aggregator as service provider model supported by the current electricity market.

The combined aggregator-BRP and prosumer as aggregator models have elements that make them well supported by the market, but other elements make these models difficult to function in the Dutch electricity market. Arrangements are in place that support aggregators to operate these models. However, complexity and expertise are two important elements that make these

models difficult to function. The delegated/broker aggregator and the DSO as aggregator models are not well facilitated in the Dutch market. Complexity in contractual agreement, lack of explicit rules and strict DSO regulation make these types of aggregator very difficult to function.

Aggregator value proposition and value capture

Empirical cases of aggregator businesses show that different kind of values are created for the prosumer and aggregator. Three kinds of value are created for the prosumer: environmental benefits, comfort and financial benefits. Increasing self-consumption of the prosumer results in environmental benefits and comfort results from enhanced control over flexibility. Value creation for the aggregator consists of mostly financial related benefits, like revenue from selling flexibility, lower electricity sourcing costs or selling a service. Flexibility can be traded and monetized in six different markets. In the TSO balancing market, by optimization of a BRP portfolio, in the day-ahead or intraday market, supplying flexibility to the DSO or TSO for congestion management and in capacity markets.

Outlook: Future of the aggregator

Disruption in the electricity market stimulates utilities to innovate and to expand their current business models. The combined aggregator-supplier type is an appropriate model for utilities to expand their proposition by including flexibility options. The aggregator as a service provider and the delegated/broker aggregator models are stimulated by advancements in ICT. Companies that focus solely on flexibility and specialize in a particular form of flexibility can use ICT to create business models that are less commodity-driven and more service orientated. The proposed new EU electricity directive support this specialization by requiring member states to adapt or create rules that lower entry barriers and provides a more transparent regulatory framework for non-combined aggregators. This same EU directive encourages active participation of prosumers. Creating and capturing value from flexibility is a process that requires substantial knowledge of the electricity market. Therefore, it is uncertain how the prosumer as aggregator model will develop in the future.

Conclusion

This thesis showed that the position of aggregator can be described in three different ways: as a new actor, a formal role and a function. The constructed typology describes six different arrangements of positioning the aggregator as an actor, how the roles are formalized and what functions are adopted by the aggregator.

Industry and technology trends are fostering developments in the direction of the non-combined aggregators. Non-combined aggregators like the aggregator as service provider, the dependent/broker aggregator, the prosumer as aggregator are benefiting from using ICT and their service-driven approach to specialize in specific forms of flexibility. This specialization assists companies to focus on the core activity of innovating and developing new ways to unlocking and commercializing flexibility. These aggregators can specialize in activities that are related to specific forms of flexibility (e.g. from EVs or home batteries). New developments relating to aggregators need to mature further, be stimulated and realized to fully benefit from its potential.

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Chapter 1

Introduction

1.1 Context and problem statement

April the 30th, 2018 has been an interesting day for discussions about flexibility in the Dutch electricity system (Duijnmayer, 2018). The Dutch transmission system operator (TSO), TenneT had to declare the state 'Alert Emergency' due to a significant imbalance between supply and demand of electricity. Electricity consumption and production forecasts of market parties deviated extensively from reality, as the amount of generated electricity was much lower than expected and consumption was higher than expected. Even though the exact cause is still unknown, one market party stated that the weather had a huge influence on this incident (Duijnmayer, 2018). The underlying cause of the problem was not so much related to the forecasted amount of generated wind and solar electricity, but the unpredictability of both wind and solar that day. Market response to balancing price signals was substantially lower than usual, while in principle adequate generation capacity was available (TenneT, 2018e). Imbalances prices rose to €401,2 per MWh for a short period but showed levels above €200 per MWh for more than five hours (TenneT, 2018e). These imbalance prices are significantly higher than normal as the yearly average imbalance price is around €20 per MWh (TenneT, 2018f)

Even though this is an example of a single case, it highlights the challenge to be expected by integrating increasing amounts of renewable energy sources (RES). The intermittent, often distributed character of renewable energy sources and the trend of electrification are fundamentally changing the electricity system. It becomes increasingly demanding to maintain the balance in the electricity system (Kondziella & Bruckner, 2016). This lead to an increasing need of flexibility in the electricity system.

A recent study by TenneT recognized this increasing demand for flexibility, as visualized in figure 1 (TenneT, 2018b). Several types of flexibility are needed and described in this study. This study showed that especially flexibility demand from market parties in the wholesale market will grow.

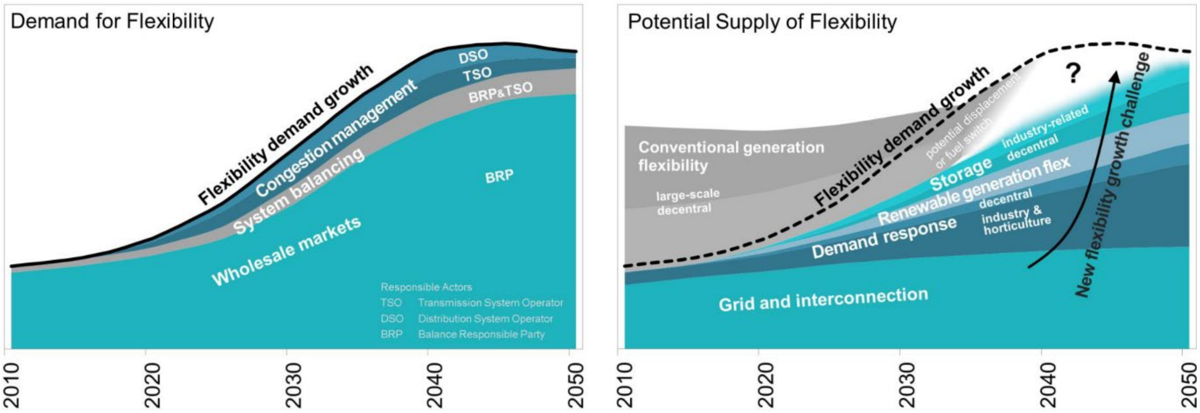

Figure 1 Expected growth of demand for flexibility and potential supply of flexibility as identified by TenneT (TenneT, 2018b)

This increasing need for flexibility needs to be provided by several technologies. Figure 1 shows a potential path of different means that provide flexibility in the electricity system. It is still uncertain how the mix of technologies and arrangements will look like in the future. In many debates the concept of 'aggregator' is raised to be a promising actor to increase flexibility or organize it. For example, Niesten and Alkemade (2015) emphasize that scientific literature highlights the importance of a new actor that is involved in creating a series of smart grid services. Several studies identify the aggregator as an actor that can provide these services (Donker et al., 2015; Eid et al., 2015; Niesten & Alkemade, 2015). However, there is no clear consensus on the definition of an aggregator, of what aggregators are and how they operate.

It is still uncertain how this aggregator will be positioned in the electricity sector as it is a new actor in the electricity system. Aggregators can play a potential role in increasing the supply of the different means of flexibility such as identified in figure 1. Aggregation of demand response or storage may lead to the availability of flexibility which would otherwise not be unlocked. Nevertheless, the necessity and importance of an entity such as an aggregator in the future electricity system are still unknown.

Current research is very much interested in the relevance and possibilities of demand-side flexibility and the role of the aggregator. The study of Burger et al. (2017) elaborates on which roles aggregators can fulfil and different types of value that aggregators can provide to the electricity system. Additionally, barriers are recognized and the need to change the market design (De Vries & Verzijlbergh, 2015). Studies have also been conducted on organisational arrangements and business models for aggregators (Lampropoulos et al., 2017; Niesten & Alkemade, 2015). However, less attention is given to the socio-technical complexity of the electricity market and the development of aggregators. In the paper of Eid et al. (2015) a more techno-institutional perspective is adopted, but it is still mainly concentrating on market design aspects.

1.2 Research objective and research questions

This research aims to provide insights into the concept of aggregators in the context of the Dutch electricity market by using both insights from the electricity market design and business models. These insights are imperative to define the importance of the developments around this new entity (i.e. the aggregator) and to have a flexible electricity system in the future. Therefore, this research also aims to contribute to a better understanding of the future role of aggregators in the Dutch electricity market. This report aims to answer the following research question:

How is the aggregator positioned in the current Dutch electricity system and how could this develop in the future?

The following sub-questions will be used to answer the main research question:

1. How is flexibility organized in the Dutch electricity system and what developments are expected in the future?
2. How is the aggregator defined in the Dutch electricity system?
3. How is the current Dutch electricity market facilitating aggregators?
4. How are aggregators creating and capturing value?
5. How will industry and technology trends influence the position of the aggregator in the future?

Insights are gained from the analyses of the current market facilitation of aggregators. Additionally, evaluating the business models of aggregators assists in determining how aggregators create value. Furthermore, the insight of analysing the dynamics and interaction of aggregators in the broader electricity system will assist in understanding possible situations of aggregators in the future. This all will result in a better understanding of the importance, practice, function and position of aggregators in the future Dutch electricity market.

1.3 Outline

This thesis is structured as follows. Directly after the introduction, chapter 2 describes the theoretical building blocks of this research. The main theoretical concepts of this research will be explained. Subsequently, chapter 3 describes the used research methods for this study. Chapter 4 describes the Dutch electricity market design and explains how flexibility is organized. In chapter 5 the aggregator concept is explained in detail and a typology of aggregators is introduced. Followed by chapter 6 where the market facilitation of aggregators is being examined. In chapter 7 it is explained how aggregators create and capture value with their business models. In chapter 8 industry and technology trends are analysed with respect to their influence on aggregators. Finally, chapter 9 and 10 present the conclusions and discussion of this thesis, respectively.

Chapter 2

Theory

Market design and business model theory are the two-main theoretical building blocks of this research. This chapter explains these two theories that form the theoretical framework that supports the analyses of this thesis.

2.1 Market design

Milgrom (2009) describes market design as follows: *"Market design is a kind of economic engineering, utilizing laboratory research, game theory, algorithms, simulations, and more. Its challenges inspire us to rethink longstanding fundamentals of economic theory."*. Market design is a relatively new but developing branch of microeconomics. The approach in market design is to turn economic theories like game theory and mechanism design into solutions for real-world problems (Kojima & Troyan, 2011).

Traditionally, economic theory took market institutions as static elements and only described the operational aspects. Two developments in economics changed this (Roth, 2007). Firstly, game theory, the study of the "rules of the game" and the strategic interactions that is evoked. Secondly, the approach of mechanism design where the rules of the game are not assumed as given, but rules are designed in such a way that certain goals or solutions are completed (Bichler, 2018). These developments led to the introduction of the market design field where an iterative approach is adopted to improve the function of markets by iterating between theory and practice. Market institutions are not perceived as static elements, but as dynamic constructs that are shaped by economic interventions (Kominers et al., 2017).

Market design is concerned with rules that guide the market and the institutions that enable transactions (Kominers et al., 2017). Rules can be interpreted broadly, ranging from common practices, professional ethics, to strict laws and regulations. Institutions can also be interpreted broadly, these can be physical, but also technological, legal or social. Jointly, rules and institutions constitute marketplaces that coordinate and facilitate transactions. Kominers et al. (2017) argue that marketplaces can run freely among market parties or can be regulated by a third party like a government. Monetary transactions can be present but is not a necessary element of a marketplace.

The fundament of market design is to question how the design of rules, regulations and institutions of a market affects the functioning and outcome of a market (Bichler, 2018). Market design takes market environments and derives designs that satisfy some design goals. Trade-offs are being analysed and market design aims for solutions that describe how an optimal organization of rules and institutions materialize.

2.1.1 Electricity market design

Market design has been practiced in a variety of fields. Applications of market design are present in radio spectrum auctioning, medical matching markets and electricity markets (Kojima & Troyan, 2011). The complexity of the electricity system and the importance of a well-functioning market has resulted in a great attention of academics to the design of electricity markets (Cramton, 2017; de Vries, 2011; Hogan, 2005; Joskow, 2008; Parag & Sovacool, 2016).

Organizing electricity markets is not a simple task. Supply and demand must continuously be in balance, thousands of resource and network constraints must be satisfied and the market should send the right incentives to motivate electricity producers and consumers (Cramton, 2017). This makes it both an economical and technically complex task to fulfil. Peter Cramton (2017) argues that the main objective that an electricity market should fulfil is to: provide reliable electricity at the lowest cost to consumers.

Society depends on a guaranteed and reliable supply of electricity. This means that there will be as little as possible involuntary load or generation shedding (Hogan, 2005). The right incentives should be in place to ensure that enough generation capacity is available. Managing all the constraints and incentives in the market is crucial for a reliable electricity system.

Cramton (2017) states that the main objective of the electricity market, to provide reliable electricity at least cost to consumers, can be broken down into two key objectives. Firstly, short-run efficiency (static efficiency), which is making the best use of existing resources. This means to optimize the use of the existing resources (e.g. generators and the transmission network) in such a way that it results in the lowest cost. Secondly, long-run efficiency (dynamic efficiency), which is ensuring that the market provides the right incentives for efficient long-term investments. In practice, this implies that there should be enough and efficient installed capacity for the supply of electricity.

Furthermore, Cramton (2003) identified other aspects, such as simplicity, incentives and fairness that are also important to have in an electricity market design.

Simplicity - The preferences and constraints of the market participants need to be understood. The essential and necessary elements in the market design can be constructed with this knowledge. A good understanding of the environment allows a simple design without errors due to oversimplicity.

Incentives – Large suppliers can reduce the quantity that they supply in order to get a higher price (Sensfuß et al., 2008). This is a problem of market power, which is exacerbated by two main factors (Cramton, 2003). Firstly, the price elasticity of demand is modest as not all consumers are exposed to real-time prices. Secondly, variability in supply and demand leads to inevitable moments of scarcity.

Fairness – A key element of fairness is equal treatment and open access to the market. Different technologies and market participants should be treated the same and have an equal possibility to enter the market.

In addition, Cramton (2003) argues that good market design begins with a good understanding of the market participants, the incentives and the economic problem that the market is trying to solve.

Boisseleau (2004) conceptualized a theoretical framework for analysing electricity markets, as can be seen in figure 2. This framework identifies three levels in the market design: industry structure, wholesale market and marketplace. The industry structure forms the first level, that describes the organization of the industry from electricity generation to consumption. The structure of the electricity industry forms the foundation of the electricity system. The responsibilities and relations between the different actors are defined. The second level describes the wholesale market, where most electricity is being traded. In the wholesale market, generators compete to serve load and prices are settled. Lastly, the third level describes the marketplace. This level describes in detail the functioning of the market and especially the rules of the game. The marketplace level describes the behaviour and operation of market participants, the competition and the price setting procedures.

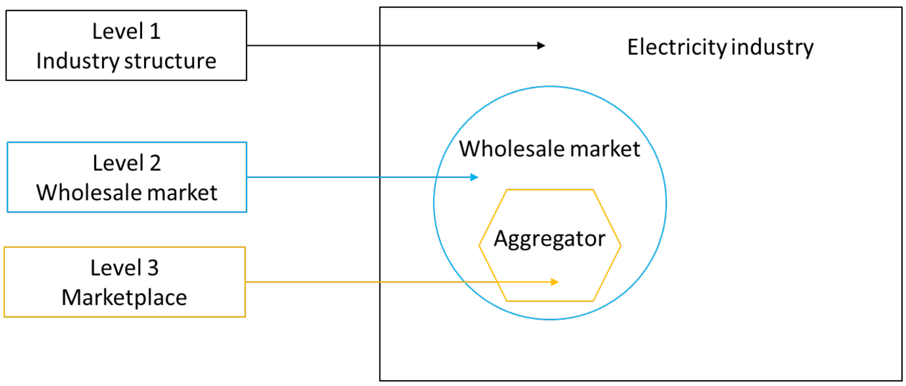

Figure 2 Theoretical framework of the electricity market design. Adapted from Boisseleau (2004)

This theoretical framework of Boisseleau (2004) will be used in this research to analyse the electricity market design in the Netherlands and the facilitation of aggregators. An analytic and not a design approach is adopted in this research. The term "electricity market design" is consequently used as an overarching concept that describes the organization of the electricity market. The first and second level of the theoretical framework of Boisseleau (2004), the industry structure and wholesale market, will briefly be analysed. Special attention goes to the third level, the marketplace. The marketplace will be extensively analysed with respect to aggregators. The operation, behaviour and facilitation of aggregators in the market design will be determined.

2.2 Business model theory

The term business model is frequently being used in the field of both academics and entrepreneurship, but a lot of ambiguity is present in the definition of the business model concept (DaSilva & Trkman, 2014). Scholars do not agree on what a business model is. As Zott et al. (2011, p.1020) state: *"…it appears that researchers (and practitioners) have yet to develop a common and widely accepted language that would allow researchers who examine the business model construct through different lenses to draw effectively on the work of others."*. There are authors that describe business models as the way a company does business while others emphasize the model aspects of business models. Several important scientific papers will be briefly described to indicate the ambiguity in the field of business model theory.

Teece (2010) argues that a business model is a conceptual model that embodies the organizational and financial architecture of a business. It outlines the business logic that a business could adopt to deliver value to customers. The element of architectural representations of a business has also been raised by Osterwalder et al. (2005). Osterwalder et al. (2005) define a business model as a conceptual tool that expresses the business logic of a firm by a simplified description and representation of what value is provided to customers. The formulation of a 'simplified description' and 'representation' by Osterwalder et al. (2005) highlights the importance of the model aspects in business models. In contrast, Rappa (2002), one of the first in defining the business model concept, defines a business model simply as the method of doing business to generate revenue. Still, many scholars argue that the business model could provide a holistic view. Chesbrough and Rosenbloom (2002) describe that a business model could explain how a company's internal structure is managed and how this is connected to the external environment. Furthermore, Chesbrough and Rosenbloom (2002) interpret the business model as a construct that mediates the value creation process, as it uses technological characteristics and potentials as inputs, which are converted through customers and markets into economic outputs.

Despite the ambiguity in the meaning of business model, Zott et al. (2011) revealed several general insights in academic literature. First, they argue that there is a widespread acknowledgement that a business model is a new unit of analysis. That it differs from products, firms and industries and that it is centred on a focal firm. Secondly, business models highlight the system level and the holistic approach to explain how business is done. Thirdly, the activities of a company play a key role in the conceptualization of business models. Lastly, business models explain how value is created and not only how it is captured.

2.2.1 Business model frameworks

Various frameworks have been developed that describe the business model in more detail, examples are the Technology-Market Mediation framework by Chesbrough and Rosenbloom (2002) or the Business Model Canvas of Osterwalder and Pigneur (2010). These frameworks describe the components, building blocks and functions of a business model. Business model frameworks do not only describe components, but also interaction among the different elements. Fielt (2013) provides a more comprehensive overview of different business model frameworks.

Business Model Canvas

One of the most well-known business model frameworks is the Business Model Canvas of Osterwalder and Pigneur (2010). A canvas representation is used to describe, visualize and assess business models. The framework consists of four areas and nine building blocks (Osterwalder & Pigneur, 2010). The areas are: the product, customer interface, infrastructure management and financial aspects. The product area describes the products that are being marketed and the value proposition that is created with the product. The customer interface area specifies which customers are being targeted, how is communicated with those customers and the relationship with customers. The infrastructure management area contains information about how the internal processes are structured in a business model. This area describes the arrangements of activities conducted, the important resources and partners in a business model. Lastly, the financial aspects of costs and revenue are described in an area.

Area	Building Block	Description
Product	Value Proposition	The Value Proposition describes the bundle of products and services that create value.
Customer Interface	Customer Segments	The Customer Segments Building Block defines the different groups of people or organizations a company aims to reach and serve
	Channels	The Channels building block describes how a company communicates with and reaches its Customer Segments to deliver a Value Proposition
	Customer relationship	The Customer Relationship describes the type of relationships a company establishes with specific Customer Segments
Infrastructure Management	Key Activities	The Key Activities comprise the most important things a company must do to make its business model work
	Key Resources	The Key Resources contain the most important assets required to make a business model work
	Key Partners	The Key Partners building block describes the network of suppliers and partners that make a business model work
Financial Aspects	Cost Structure	The Cost Structure block describes all costs incurred to operate a business model
	Revenue Streams	The Revenue Streams represents the cash a company generates from each Customer Segment

Table 1 Description of the areas and building blocks of the Business Model Canvas (Osterwalder & Pigneur, 2010).

The nine building blocks together form the business model, that is being described by Osterwalder and Pigneur (2010) as the 'blueprint' to implement in structures, processes and systems of a company.

2.2.2 Value creation and the value proposition

The most important building block of the Business Model Canvas that will be used in this research is the value proposition. The value proposition building block describes the benefits that a company offers to its customers (Osterwalder & Pigneur, 2010). The value proposition describes the 'what's in it for me' (from a customer perspective) that the bundle of products and/or services from a company provide. The creation of value is very important in the value proposition. Customers appreciate benefits that will result from a product or service. Therefore, value creation is an essential element of a business model.

Value creation in a smart grid context

Niesten and Alkemade (2015) conducted an extensive review of literature and pilot projects to analyse business models and the value propositions for stakeholder involved in smart grid services. One of the conclusions of this research is that in the context of smart grids new business models are being created that allow companies to create and capture value by offering smart grid services.

An overview of different values for different stakeholders is being introduced by Niesten and Alkemade (2015). They present values for prosumers, system operators and aggregators that result from these smart grid services. An overview of these values is presented in table 2.

Value for prosumer	Value for system operator	Value for aggregator
Environmental benefits	Improved system reliability & stability	Revenues from selling flexibility
Financial benefits	Optimized grid operation	Lower sourcing costs for electricity retailers
Enhanced control over energy consumption and bill	Reduced system cost	
Customer comfort	Reduced peak demand	
Increased participation in the electricity system	Improved grid operation	

Table 2 Adapted overview of values from literature and pilot project review by Niesten and Alkemade (2015)

Chapter 3

Methods

This chapter explains the way this research was conducted. The following sections describe how the different sorts of data have been collected, analysed and validated in this thesis.

3.1 Data collection

A mixed methods approach has been adopted in this research, by combining several research methods. Data has been collected using literature review, interviews and a short survey.

3.1.1 Literature review

Qualitative data were collected iteratively, started with an explorative study of relevant literature about electricity markets, flexibility and aggregators followed by more in-depth research. Recent literature, where the concept of the aggregator had been used, was studied thoroughly and further research was often founded by following used references. Furthermore, the literature provided by the supervisors contributed to the enlargement of the literature base. Especially the in-depth research part consisted of data collection by conducting semi-structured interviews with experts in the field of electricity markets and aggregators.

Scientific and non-scientific literature was gathered to gain a comprehensive understanding of the topics in the field of the Dutch electricity market design, issues concerning flexibility of the electricity system and the meaning of the aggregator concept. Scientific literature has been mainly collected by using the scientific search engine Web of Science. Grey literature like reports, policy documents and other relevant information were often gathered by extensive research on the web. Energy related news articles have been used to stay informed of the most current discussions. Additionally, information gathered from discussions and dialogues with experts at TenneT was used to support this research. The reference management tool Mendeley has been used to file the literature appropriately to use the richness of the collected data at its best.

3.1.2 Semi-structured interviews

In total twelve semi-structured interviews were held to gather the most comprehensive insights for this research. Participants were asked to read and sign the informed consent form that described the purpose and procedures regarding the interview, a copy of this form can be found in appendix C. An overview of interview participants can be found in appendix D. Interview participants consisted out people employed at research institutes, grid operators, utilities, aggregator companies and at policy making level. An interview guide has been constructed and used during the interviews, see appendix B. Questions were constructed by the identification of knowledge gaps of the researcher and by finding ambiguities in literature where the expression of the vision of interview participants could be useful. The semi-structured basis resulted in several questions that were asked during the interview. However, the interviewer made sure that interview participants could elaborate as much as possible on topics that were found relevant by the interviewee. This made sure that rich and diversified information was collected during these interviews.

3.1.3 Survey ranking

Survey data is collected in this study by asking interview participants to fill in two different rankings. These rankings are attached to the interview guide in appendix B. These rankings were constructed by using the insights gathered during the literature review.

The first ranking consists of different types of aggregators, which resulted from the typology that has been constructed in chapter 5. Participants were asked to rank the types of aggregator according to how well they believe the Dutch electricity market design is facilitating this type. Participants needed to rank the five aggregator types with 1 being the best-facilitated type and 5 the worst facilitated type. The ranking question was asked for two different moments in time. Firstly, participants were asked how the types are facilitated at this moment within the current market design. Secondly, participants were asked to express their outlook on the facilitation of the aggregator in the future (i.e. around 2030). In total nine participants completed the ranking.

A second ranking was requested from interview participants that concerned the business model of aggregators. Participants were asked to rank electricity markets according to the appropriateness for aggregators, so which market is opportune for an aggregator to participate in. Similarly, to the first ranking, rank 1 is being the most appropriate and 6 the least appropriate market. Again, rankings for two different moments in time was requested, at this moment in time with current market circumstances and an outlook into the future at 2030. A total of ten participants completed this ranking.

3.2 Data analysis

This research used three main sources of data: literature, interviews and survey rankings. Consecutively the analysis of these data sources will be explained.

3.2.1 Literature review

The scientific and non-scientific articles and reports were first briefly read to identify important sections. Secondly, important phrases or concepts were highlighted to indicate the importance which could be easily located in a second read. Multiple annotations were made which later were used in the analyses.

Especially for answering the first two sub-questions, reviewing literature were extensively used. Secondary data analyses were used to gain a thorough understanding of the matter. Extensive study of literature by analysing material and search for additional information was necessary to gain a comprehensive understanding of the literature. The analysis of the second sub-question, defining the aggregator concept in the Dutch electricity system, is primarily based on an extensive but non-exhaustive list of stakeholders and their definition of the aggregator concept. Secondly, results from the semi-structured interviews were used to complement this list (data analysis of the interviews are described in the following section)

3.2.2 Interviews

Researching sub-question three, four and five depend on the data gathered through the interviews. Therefore, a well-structured method was used to analyse the data gathered through the interviews.

Firstly, the interviews were all recorded with an audio recording device. These recordings were transcribed with the use of the ATLAS.ti qualitative data analyses software. The written transcript was synchronised with the audio recording by placing audio/text anchors, this simplified re-listening specific parts of the audio recording. The correctness of the transcript was verified by rereading the text multiple times.

Secondly, after converting the audio recording into a transcript, the transcript was coded. A general code structure has been constructed beforehand, based on the interview guide and the questions. Furthermore, additional codes were added in the coding process because some information was out of the scope of the general codes. The individual codes were grouped by overarching themes. After all, a total of seven overarching theme codes were constructed. A printout of the results of the coding was used in the subsequent steps of the research.

3.2.3 Survey ranking

Rankings were recorded analogue on printouts and needed to be digitized for further analyses. Results were entered in a spreadsheet to simplify the further analysis. Data were scanned for inconsistencies and double checked with the analogue inputs.

A box-and-whisker plot or boxplot is a simple statistical technique that has been used to analyse and visualize the rankings. The boxplot is an often used method to visually summarize and compare groups of data (Tukey, 1977). The mean, the median, the approximate quartiles and the lowest and highest data points visualize the spread, symmetry and distribution of data in a boxplot. Outliers can also be easily identified by a boxplot. The boxplot is especially useful for this dataset for the ease of comparison. Distribution of data and means are easily comparable with the use of boxplots.

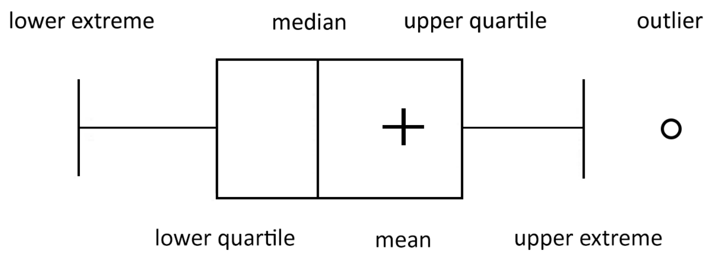

Figure 3 Explanation of box-and-whisker diagram. Adapted from Tukey (1977)

The boxplots in this thesis have been created by using several functions and data visualization tools that are present in Microsoft Excel.

3.3 Research validation

Several research validation methods have been used in this thesis. Peer-reviewing, interviews and attendance of conferences have been used to guarantee research reliability and validity. The research approach and intermediary results have been evaluated in an iterative way and commented on by the thesis supervisors of this research. This resulted in interactively increasing the quality of both the research approach and guaranteeing data validity. The data gathering method of interviews has been validated by reviewing the interview guide with the supervisors of this thesis. Ranking questions have been improved with the help of peer-reviews, that resulted in more precise and reliable data gathering. Furthermore, during the data gathering period of conducting the interviews, the interview guide and the accommodating question have been improved based on input and the proceeding of the interviews. The formulation of questions and explanation of questions was adjusted according to experiences in several of the first interviews.

Multiple aggregator and flexibility conferences have been attended in both the Netherlands, Copenhagen and Brussels. Participating in these conferences has taken place in both the exploratory part of this research, to explore relevant topics concerning the aggregator concept and flexibility and to gain a more comprehensive understanding of the field, as well as to verify results with international experts in the field of flexibility and aggregators. Additionally, gathered data at these conferences enhanced the insights by using the perspective of an audience that was both nationally and internationally orientated.

Combining the data from diverse sources was used for data triangulation. The combination of the qualitative data sources of scientific literature, grey literature and interviews in combination with the survey rankings were used to validate results and provide a more detailed and balanced picture of the subject in the way Altrichter et al. (1993) argue in their book. The results of the rankings have been validated by using extensive literature review to confirm argumentations and vice versa, argumentation retrieved from literature review is validated with the gathered quantitative data.

Chapter 4

Flexibility in the Dutch electricity system

This chapter provides a brief overview of the current Dutch electricity market design and how flexibility is organised. It is important to get a solid understanding of these fields for the further research steps that are undertaken in this thesis. Therefore, the issue of flexibility in the electricity system and the market design will first be analysed, which will answer the first sub question of this research: *How is flexibility organized in the Dutch electricity system and what developments are expected in the future?*

The Netherlands is aiming for a sustainable and low-carbon energy system, as agreed by more than forty organization in the Energy Agreement (SER, 2013). In 2017 the production of renewable electricity has grown by 10 percent (CBS, 2018). The share of renewable electricity has grown from 12,5 percent in 2016 to 13,8 percent in 2017 and is expected to increase much further. The Energy Agreement contains ambitious targets for the proportion of energy generated by renewable sources. The latest evaluation of the developments regarding this Energy Agreement revealed that it is expected that the share of renewables in the electricity mix will grow to 28 % in 2020 and further increase in 2025 to 57 % (ECN, 2017b). This increase in electricity produced from renewables will have an impact on flexibility, as will discussed further on. The foundation of flexibility in the electricity system lies within the design of the electricity market. Therefore, the electricity market design is first analysed followed by a review of flexibility.

4.1 The Dutch electricity market design

In the mid-1990s the Dutch electricity system started to liberalize (van Damme, 2005). This liberalization process restructured the roles and responsibilities of actors in the electricity system. De Vries et al. (2012) constructed a framework to visualize the design of the current electricity system. This framework is illustrated in figure 4.

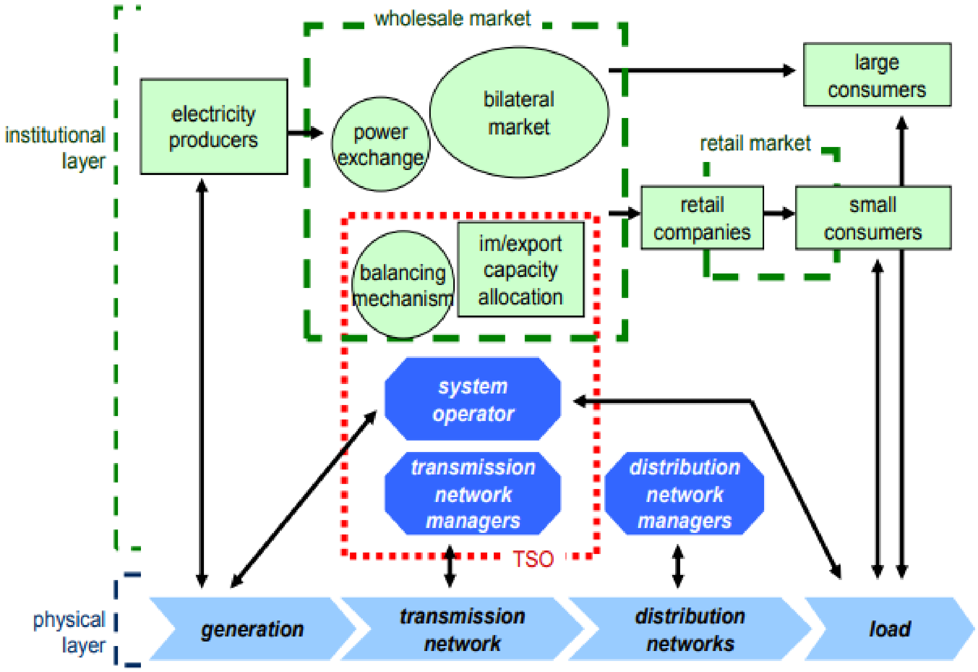

Figure 4 Organization of the electricity system in the Netherlands (de Vries et al., 2012)

Different actors control different parts of the electricity system. De Vries et al. (2012) made a distinction between the physical side and the institutional side of the system. The physical layer consists of the physical chain through which electricity flows. Electricity is generated and transported through the transmission and distribution grids and eventually consumed at the load side. The institutional layer consists of the actors who control the components in the physical layer and other parties involved in the electricity system.

The double-pointed arrows in figure 4 indicate which actors control which part of the physical layer. The arrows with single points indicate the direction of electricity trade. An elaborate description of the electricity system and important actors can be found in appendix A.

4.2 What is flexibility

Issues concerning flexibility have often been mentioned as one of the key technical issues that arise with the integration of (decentral) variable renewable energy (VRE), in particular wind and solar (Huber et al., 2014; Lund et al., 2015; Ma et al., 2013). However, there are different ideas about what flexibility means in an electricity system context. Lannoye et al. (2012) define flexibility as: *"the ability of a power system to deploy resources to respond to changes in the remaining system load that is not served by VRE"*. Moreover, Ma et al. (2013) describe flexibility as both an issue at the generation and demand side. Ma et al. (2013) define flexibility as *"the ability of a power system to cope with variability and uncertainty in both generation and demand, while maintaining a satisfactory level of reliability at a reasonable cost"*. The increasing integration of VRE makes generation more prominent in the definitions of flexibility (Ma et al., 2013). TenneT (2018) has a broader definition of flexibility as it sees flexibility as: *"the means that enable change from one state of equilibrium between generation and consumption to* *another*". Overall, it can be argued that flexibility is related to the need or ability of the electricity system to cope with changes that occur in both generation and demand.

Traditionally the electricity system in the Netherlands is based on mainly large central power plants. These power plants supply electricity and provide flexibility. Historically, the pool of power plants followed the variations in the net demand for electricity (the load) by adjusting generation output. The demand for electricity has variability characteristics, as the demand for electricity fluctuates over time, this is so-called *variability* (Ma et al., 2013). However, it can occur that there is an unplanned outage of a generating unit or errors in generation forecasts. This is unpredictable and therefore results in *uncertainty*. Traditionally, large central power plants were designed to provide enough flexibility to cope with variability and uncertainty in supply and demand (Ma et al., 2013). Increasing amounts of generation capacity from VRE sources requires the system to be able to cope with variability and uncertainty associated with these sources.

4.3 Current flexibility in the Dutch electricity system

4.3.1 Demand for flexibility

Currently, most of the produced electricity in the Netherlands is being produced with fossil-fuelled generators. Around 81 % of the generated electricity in 2016 has been produced with fossil fuels and the share of VRE sources, like wind and solar, was almost 9 percent (ECN, 2017b). Flexibility demand due to VRE sources is still limited because the share of VRE is still limited. The majority of flexibility is needed due to variability in the load and less due to variability in VRE generation (ECN, 2017a). An indicator of flexibility demand due VRE is the difference between the level and variations in total load and residual power load. Residual power load is defined as the total electricity demand minus the generation of electricity from VRE sources (Huber et al., 2014). Hence, the residual power load needs to be covered with conventional generation.

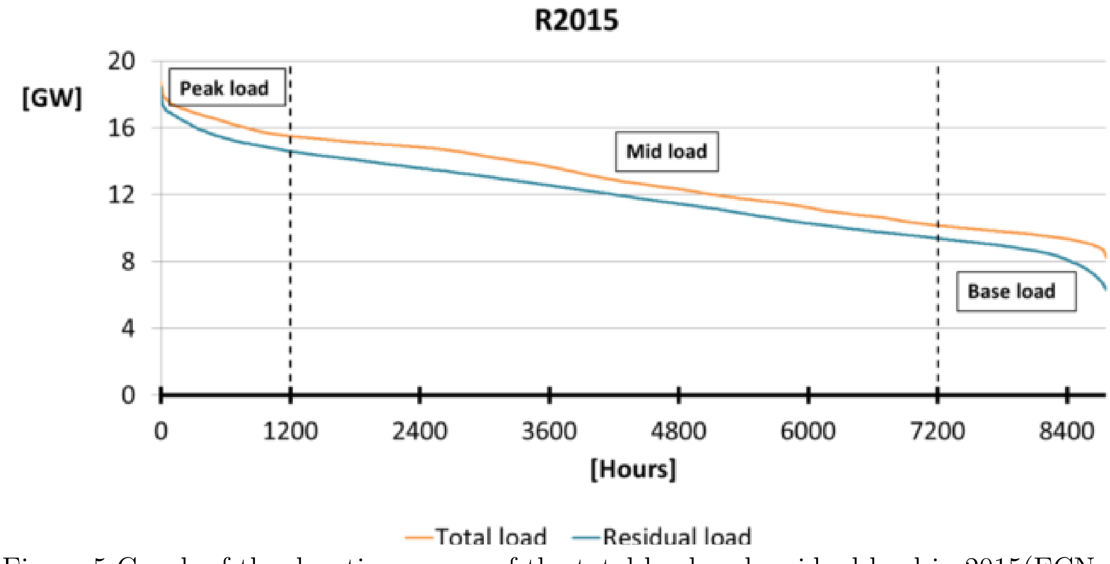

Figure 5 Graph of the duration curves of the total load and residual load in 2015(ECN, 2017a)

Figure 5 indicates the load curves of the total load of electricity and the residual load in 2015. These curves illustrate how many hours a certain capacity of electricity supply is needed to match the (residual) electricity demand. From this figure, it can be concluded that the difference between residual load and total load is minimum. The maximum difference between total load and residual load is 2 GW compared to a maximum load of 18 GW (ECN, 2017a). In 2015 (and still in 2018) the supply of electricity from VRE sources is relatively low, therefore the level and variation of residual load are largely similar to the level and the variation of total load. Therefore, currently flexibility is mainly needed to cope with variability and uncertainty in the load, and to less extent due to variability and uncertainty in VRE generation.

Flexibility demand originates from *variability* in demand and supply or as a result of *uncertainties*. The demand for flexibility as a result of *variability* is mainly noticeable in hourly variations and therefore mostly in day-ahead markets (Ma et al., 2013). Whereas flexibility demand due to *uncertainties* is more apparent on a shorter timescale and is more present in the intraday and balancing markets.

Variability

Electricity demand (electricity load) variates over time. Hourly load variations exist because electricity demand varies throughout the day. In figure 6 it is displayed that the load differs among consecutive hours. These variations in load result in the need for flexibility. Hourly load variations or 'ramps' (can be both in upward and downward direction) are major indicators of the flexibility or 'ramping' needs due to variations in the (residual) power load (ECN, 2017a). A study conducted by ECN analysed the need for flexibility in 2015. They estimated that, due to hourly variations in the load, a maximum hourly ramp-up and ramp-down of 3.0 GW/h and 3.1 GW/h was necessary in 2015 (ECN, 2017a). This results in a total annual hourly ramp need (i.e. the total annual energy of hourly ramps aggregated over a year) in both upwards and downwards direction, of 2.2 TWh.

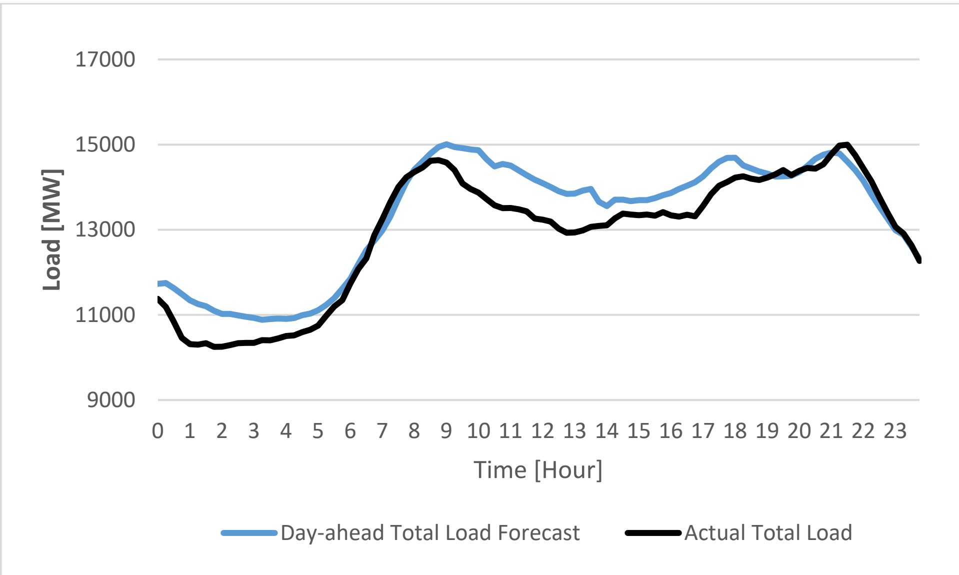

Figure 6 Example electricity grid load profile. Forecast and actual load in the Netherlands for 23.04.2018. Data retrieved from ENTSO-E Transparency Platform.

Uncertainty

Next to flexibility demand due to variability, there is also a need of flexibility to cope with *uncertainties*. Wind forecast errors or outages of conventional generators are examples of *uncertainties* that result in a need of flexibility. This flexibility demand is not on hourly basis but on a shorter timescale. Hence, this is called flexibility on the intraday/balancing market. It is estimated that the demand for flexibility due to the forecast error of wind generation in 2015 was maximum 1.1 GW/h in both upward and downward direction, which resulted in an annual demand of 0.7 TWh in upward direction and 0.4 TWh in downward direction (ECN, 2017a). However, these estimates are very rough and the flexibility demand due to uncertainties in conventional generation (e.g. unplanned outage of generator) are unknown. Nevertheless, the volume of imbalances that are regulated by the TSO gives some magnitude of flexibility demand due to uncertainties, as ancillary services are the final option to cope with flexibility due to uncertainties. The total absolute imbalance volume was 1.1 TWh in the Netherlands in 2017 (TenneT, 2018f).

4.3.2 Supply of current flexibility

The electricity generation capacity in the Netherlands consists of a range of technologies and sources. The majority of generation capacity is fuelled with coal (15 %) and natural gas (67 %), as also displayed in figure 7 (TenneT, 2018f).

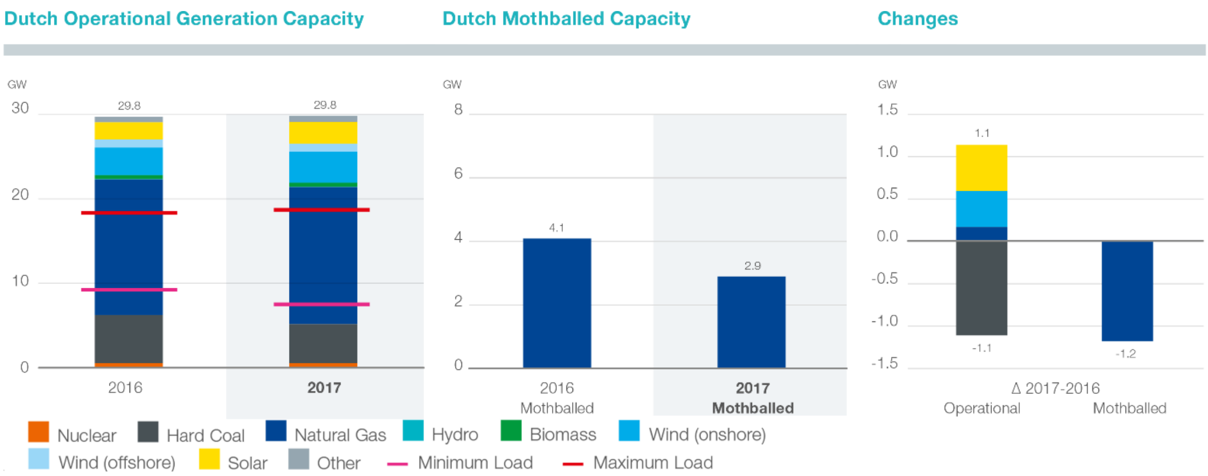

Figure 7 Operational and mothballed electricity generation capacity in the Netherlands in 2016 and 2017 (TenneT, 2018f)

Variability

Hence, coal and gas are predominately meeting the hourly flexibility needs. A scenario study by ECN estimated that the total annual need for demand for upward/downward flexibility (i.e. 2.2 TWh in 2015 with ramps of around 3 GW/h in both directions) was met 49 % by gas and 42 % by coal in 2015 (ECN, 2017a). Another study from 2012 analysed that decentralized combined heat and power (CHP fuelled by natural gas) generators are an important source of flexibility (Hout et al., 2014). The horticulture sector in the Netherlands is an active participant in the market with CHP in combination with demand response. They provide a substantial amount of flexibility, it is estimated that they have installed around 0.5 GW of flexibility (TenneT, 2018b).

Next to generation capacity also interconnectors with neighbouring countries are a source of flexibility. Interconnectors can provide flexibility by balancing large local differences in supply and demand (Lund et al., 2015). Currently there are nine interconnectors within the electricity grid of the Netherlands, connecting to the grids of Germany, Belgium, Great Britain and Norway (TenneT, 2018f). Additionally, a subsea cable between Denmark and the Netherlands is currently being build and expected to be operational in 2019. It is estimated that these interconnectors supply around 9 % of upward/downward hourly flexibility by means of net imports (ECN, 2017a).

To conclude, coal and natural gas are the main supply options to meet the demand for upward/downward flexibility that is caused by hourly variations. Secondly, interconnectors also provide significant amounts of flexibility.

Uncertainty

Next to hourly flexibility, there is also a need for flexibility due to uncertainties. This demand for flexibility is present on a shorter timescale due to unpredictability in forecasts and unplanned generation outages. This results in flexibility demand on the intraday and balancing market. The scenario study by ECN argues that the incumbent conventional generators can easily meet this flexibility demand (ECN, 2017a). Unfortunately, there is no data or study available on the present sources of flexibility due to uncertainties. TenneT does not register the type of fuel or energy source of supplier of balancing products.

4.4 Flexibility compared to the international situation

Ecofys (2016) has analysed several countries on various elements to indicate the flexibility of the electricity system. Figure 8 displays a comparative chart of the results of this study for the flexibility of the Belgian, German and Dutch electricity system. From this chart it can be concluded that the Netherlands has a well-developed interconnector infrastructure and wholesale market. However, the neighbouring countries score significantly higher on storage. The Netherlands has due its geography a low potential for (pumped) hydro-electric power stations, whereas, Belgium and Germany already have a significant installed capacity of these kinds of stations (Ecofys, 2016).

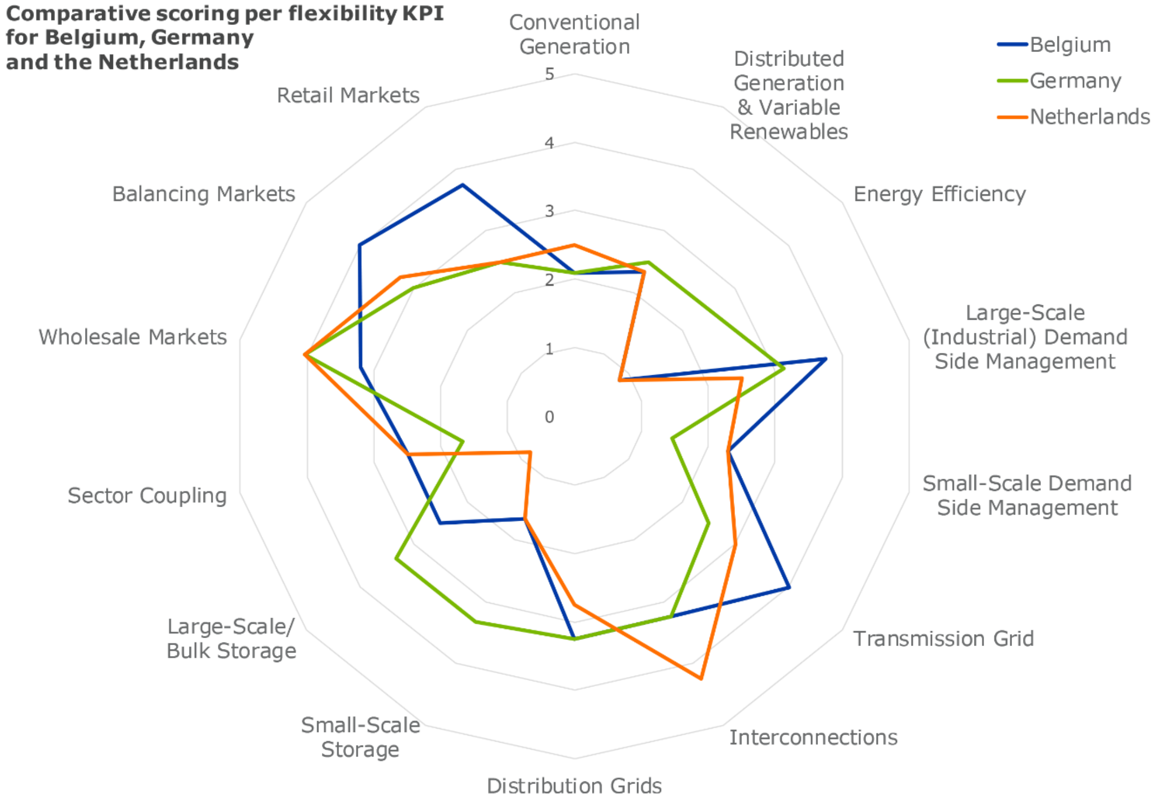

Figure 8 Flexibility chart of Belgium, Germany and the Netherlands based on comparative analyses of flexibility of the electricity system. Score ranging from level 1: low readiness to level 5: high readiness (Ecofys, 2016).

The above chart presents only one possible method that indicates the flexibility of a countries electricity system and to compare it with those of neighbouring countries. Next to this method, several other methods exists that indicate the flexibility of a countries electricity system (Fraunhofer IWES, 2015; Yasuda et al., 2013). However, figure 8 highlights that the Dutch electricity system has many aspects present that makes the electricity system flexible.

4.5 The future of flexibility in the Dutch electricity system

Several studies have been conducted to analyse the demand and supply of flexibility in the future (up to 2050) Dutch electricity system (ECN, 2017a; Hers et al., 2016; Hout et al., 2014). Some important elements have been identified in these studies

4.5.1 Developments in future flexibility demand

As described before, the flexibility demand due to VRE generation is still limited in the Netherlands, as the share of VRE is still limited. Most flexibility is needed due to variability in the load instead of variability in VRE generation. However, the electricity system in the Netherlands is changing rapidly, as increasing amounts of VRE (i.e. especially offshore wind) is being installed. It is expected that the share of renewables in the electricity mix will increase to 28 % in 2020 and further increase to 57 % in 2025 and 87 % in 2035 (ECN, 2017b). This will have a significant impact on the variability of the electricity generation and therefore increasing flexibility needs. ECN (2017a) estimates that the total annual demand for flexibility more than doubles between 2015 and 2030. Another study conducted by Hers et al. (2016) estimates an increase of 30-40 % in flexibility demand in 2023 compared to 2013. Furthermore, the largest growth in flexibility demand is expected to happen between 2030 and 2050. A tripling (factor 3) of flexibility is expected between 2030 and 2050 (ECN, 2017a). Several causes for this increasing demand for flexibility have been identified, these will briefly be discussed.

Increasing supply side variability and uncertainty

One of the first challenges arises with the increasing share of VRE. As described before, traditionally the *variability* of the electricity system is mainly related to the demand side. However, VRE introduce more *variability* at the generation side. The electricity output of VRE sources, such as wind turbines or photovoltaics, show frequent and natural fluctuations, which result in more variability at the generation side (Huber et al., 2014). There are also unavoidable discrepancies between wind and solar power forecasts and the actual output, subsequently resulting in an increase of *uncertainty* at the generation side (Ela & O'Malley, 2012). It is agreed by many that increasing integration of VRE results in an increasing demand for flexibility (Denholm & Hand, 2011; Ela & O'Malley, 2012; Fraunhofer IWES, 2015; Huber et al., 2014; Kondziella & Bruckner, 2016; Lund et al., 2015; Ma et al., 2013; Nicolosi & Fürsch, 2009).

Electrification

Demand for electricity is increasing as the heating, transportation and other sectors are increasingly using renewable electrical energy instead of carbon based energy (ECN, 2017b). This so-called 'electrification' means shifting away from the use of fossil fuels to electricity. Consequently, peaks in the electricity consumption arise which become problematic as the electrification continues (Powells et al., 2014). Especially the uptake of heat pumps and electric vehicles (EVs) is expected to increase peak demand (Bobmann & Staffell, 2015). Additionally, the overall electricity load will increase due to the increasing demand for electricity. The electrification results in more variability of the load/demand which results in the need for more flexibility. However, these sources (i.e. heat pumps, EVs) could potentially act as flexible demand and therefore they could provide a noteworthy amount of flexibility (Papadaskalopoulos et al., 2013).

Conventional generation capacity displacement
The rise of VRE impacts the installed base of conventional generation plants. Increasing amounts of electricity from VRE sources could displace conventional power plants as the utilization time of the conventional generators is going to be reduced and the profitability decreases (Ma et al., 2013; Nicolosi & Fürsch, 2009). This reduces the overall flexibility of the power system, as flexible conventional generation capacity could be taken offline, as they are no longer providing economically viable. In the German power system similar effects are already present (Nicolosi & Fürsch, 2009). Nevertheless, on long term peak and flexible generators are required to ensure system reliability and flexibility to cope with increasing fluctuations.

Congestion
Large scale integration of renewable energy sources has consequences for the use of the existing electricity network infrastructure. Electrification and the decentral nature of renewables impact both the transmission and distribution grid. The increase in electricity demand and the simultaneity character of this demand results in increasing loads on the electricity grid (Hers et al., 2016). This all can lead to congestion. Congestion is defined by the ACM (2015a) as a situation in which the predicted maximum transport capacity of a grid section is not sufficient to meet the need for transportation.

Congestion is especially expected at the distribution grid level (Hers et al., 2016). The FLEXNET project of ECN (2017a) calculated that based on their scenarios less than 10% of the assets will be overloaded until 2030. In absolute numbers, these overloads will lead to a significant amount of work and a challenge for grid operators. Beyond 2030, the incidence is more significant. The same study of ECN (2017a) expects 35% of distribution transformers and 45% of the substation transformers to be overloaded in 2050. Most assets will likely be replaced due to assets ageing. The right investment strategy will therefore limit overloading assets.

Grid reinforcements can prevent congestion. However, reinforcing the grid is a complex task that requires time and capital consuming efforts from DSOs. Developments in increasing demand for transport capacity could catch up the ability of DSOs to implement grid reinforcements in time. This could lead DSOs to consider using flexibility as a (temporarily) means to prevent congestion (Hers et al., 2016).

In conclusion, there are four main drivers for an increasing demand for flexibility. First of all, the variability and uncertainty in VRE result in the need for more flexibility. Secondly, the overall load will increase due to electrification. Peaks due to electrification results in more variability and the need for more flexibility. Thirdly, VRE could potentially displace conventional generation capacity, which is currently an important supplier of flexibility. VRE sources have a limited potential in the supply of flexibility and new sources should substitute this flexibility demand. (Lund et al., 2015). Lastly, congestion at the distribution grids may result in additional demand for flexibility. This all results in the need for increasing amounts of flexibility and flexibility from new sources.

4.5.2 Potential future sources of flexibility

Next to changes in the demand for flexibility, the supply of flexibility can also change. Currently, there are many developments taking place at the supply side of flexibility. Some of the most important developments are: interconnectors, conventional generation and demand response and storage. These developments will be briefly discussed in the following paragraphs.

Interconnectors

The capability of transmitting electricity and especially international connections ("interconnectors") can be an important source of flexibility (Schaber et al., 2012). As a good transmission network with interconnectors can balance local differences in supply and demand. The smoothing of spatial electricity fluctuations is providing flexibility (Lund et al., 2015). Several authors claim that in future years cross-border trading and net import will become more important in providing flexibility (ECN, 2017a; Hout et al., 2014). The study conducted by ECN (2017a) is even estimating that net import will be the dominant source of flexibility, with ranging between 40-70 % of overall flexibility need in the period 2023-2050. However, some important remarks should be made. First of all, the same report by ECN (2017a) states that the amount of flexibility provided with net import highly depends on assumptions of expansion of interconnection capacities across the EU28+ countries and especially between the Netherlands and its neighbouring countries. Secondly, the amount of flexibility gained from interconnectors heavily depends on a well-designed and functioning market (Lund et al., 2015). Thirdly, the study by ECN (2017a) has not included internal grid constraints in their analyses. Internal network constrains is in some cases more critical than available interconnector capacity (Brancucci Martínez-Anido et al., 2013). Internal grid constrains could limit available interconnector capacity and limit the flexibility contribution.

Conventional generation

It is highly uncertain what the role of flexibility from conventional electricity generation will be in the future. As some studies expect limited supply by conventional generators, while others highlight the importance.

A study by Hers et al. (2016) states that conventional power plants in combination with industrial demand response can supply the necessary flexibility until 2023. However, after 2023 the limits of flexibility supply by the current generation facilities will be reached. New sources of flexibility are necessary after 2023 (Hers et al., 2016). A study by ECN (2017a) reports that they expect a rapid decline in the share of flexibility provided by conventional generation. They expect that the share of gas falls to 30 % and coal to 5 % in 2023, while in 2050 the combined share of coal and gas will be between 6-30 %.

However, others argue that conventional power plants, especially gas power plants, stay important in the future electricity system. For example, Joode (2015) argues that natural gas in combination with biogas could play an important role in delivering flexibility, with or without carbon capture and storage (CCS). Furthermore, conventional power plants can be used to produce electricity from hydrogen. However, the use of hydrogen in power plants is still in the research and development phase.

The current Dutch government agreed in its coalition agreement that coal-fired power plants will be phased-out by the end of 2030 at the latest (Rutte et al., 2017). Additionally, they also agreed to introduce a minimum price for CO_2 emissions. Both intended measures result in much uncertainty about the future of conventional power plants. The major electricity producers in the Netherlands recently warned that many gas-fired power plants will close as a result of the intended measures (Savelkouls, 2018).

Overall, it is highly uncertain what the role of conventional generation will be in supplying flexibility. It is a very delicate subject and decision making in the political arena will most likely influence the future of flexibility by conventional generation.

Demand response and storage

There is also flexibility present at the demand side. Flexibility at the demand side involves electricity consumers adapting their consumption regarding the quantity and/or the timing of use, this is called demand response (Palensky & Dietrich, 2011). Some examples of demand response are: smart charging of electric vehicles (EVs), controlling heat pumps, industrial demand response and other residential demand response.

ECN (2017a) estimates that demand response (industrial and EVs) could provide 10-30 % of the desired flexibility in 2030-2050. However, estimates are very difficult to make as demand response mainly depends on behavioural aspects, which are hard to predict. On the other hand, the potential of flexible capacity at the demand side is growing significantly in the upcoming years (Slingerland et al., 2015). The electrification of some sectors (e.g. transport and heating) results in additional (flexible) electricity demand that could be used in providing flexibility.

In addition to the demand response technologies, electricity storage is a potential provider of flexibility. ECN (2017a) identifies a limited role for stationary storage (battery storage, compressed air, superconductors, etc.). This has mainly to do with the fact that there is a large potential of other, alternative flexibility options that are (much) cheaper to meet flexibility needs. Although, many others argue that storage, predominately battery storage in EVs (which could also be a form of demand response), has much potential (Denholm & Hand, 2011; Grünewald et al., 2012; Lund et al., 2015; Papadaskalopoulos et al., 2013).

New entrants

One of the trends in the electricity system is the increasing number of actors active in the market. The number of decentral consumer assets (generation, demand response and storage) is and will increase further in upcoming years (Slingerland et al., 2015). Eid (2017) describes a couple of examples of how this is already visible, such as the rapid growth of initiatives started by citizens to locally produce and trade renewable electricity. The prosumer is another example of a new entrant that could potentially provide flexibility. Either these new actors or the different form of participation has potential to form new sources of flexibility.

4.6 New opportunities arising from developments in market design and flexibility

Developments in the market design, like the rise of new markets, and the transformation of the flexibility landscape results in difficulties but also leads to new opportunities. New forms of flexibility are being developed, which could come from new technologies but also from new actors.. Niesten and Alkemade (2015) emphasize that scientific literature highlights the importance of a new actor that is involved in creating a series of smart grid services that are necessary due to these developments. The concept of an aggregator is called by many as such a new actor or solution to unlock (new) flexibility, to organize it within the market design and to create value from it (Donker et al., 2015; Eid et al., 2015).

Chapter 5

Defining the aggregator concept

This chapter focusses on clarifying the aggregator concept and to describe how the aggregator is defined in the Dutch electricity system. The following analyses and developed typology will result in answering the second sub-question: *How is the aggregator defined in the Dutch electricity system?*

5.1 Establishing of the aggregator concept

It is important to understand the context of the aggregator to comprehend the aggregator concept. The context of the aggregator contains objectives that are envisioned to be realized with the aggregator concept. The development of the aggregator concept is not an end in itself. The aggregator concept is a means that could assist realize the greater objective.

The Dutch electricity system is transitioning from a centralised fossil fuel generated system towards a system with increasing numbers of decentralized renewable energy resources (ECN, 2017b). The Ministry of Economic Affairs (2016) defines the objective of this transition in the electricity system as to decarbonize the electricity system and to assure affordability, reliability and safety. Reliability and safety have a lot to do with flexibility. Flexibility makes sure that the balance between supply and demand can be guaranteed and result in a safe and reliable electricity system. In the previous chapter it was described that the role of flexibility and unlocking new options of flexibility is becoming increasingly important with the integration of more variable renewable energy in our energy system. Mechanisms need to be developed to foster the development of flexibility, to make sure that the electricity system can cope with the increasing amounts of renewable energy. The aggregator concept is one of those mechanism that could unlock flexibility.

The aggregator concept is recognized by many as a means that could assist in realizing the above stated objectives, to unlock more and new options for flexibility (Dietrich & Weber, 2017; Eid et al., 2016; Verhaegen & Dierckxsens, 2016). The aggregator concept is used to illustrate both the activity of aggregation and the entity of new intermediary. Aggregation is a function taken by a legal entity that aggregates the flexibility of prosumers in order to offer in turn to offer to other electricity system participants (Altmann et al., 2010). An aggregator is a possible legal entity that could adopt this function and act towards the grid as one party (Smart Grid Task Force, 2013). The function of aggregation is becoming increasingly important. Aggregation is required to unlock the flexibility potential of many small flexibility technologies. Most consumers do not have the means to trade directly at the electricity market and could use the services of an aggregator to assist the consumer in the complexity and participation in the electricity market (Eid et al., 2015). Several authors and organizations argue that a new market intermediary like the aggregator is necessary to activate the full range of customers and their flexibility (Eid et al., 2015; Ministerie van Economische Zaken, 2016a; Stifter et al., 2016; USEF Foundation, 2015a). The following section will give a non-exhaustive overview of definitions of the aggregator concept.

5.2 What is an Aggregator

The definition of an aggregator is still very ambiguous. In scientific literature, professional papers and policy documents there is no consensus on the definition of an aggregator and what such an aggregator should be doing. The concept of aggregator is defined and described differently by different stakeholders. An overview is made of relevant stakeholders that describe the aggregator concept and their perception on the concept aggregation is being described.

5.2.1 Scientific literature and other research

Eid et al. (2015) reviewed the European market design for demand-side flexibility. In their analyses, they pay attention to the concept of aggregator. They define the aggregator as an actor, a new market intermediary that commercialize the potential of demand response at the full range of customers. Koponen et al. (2012) continue with this reasoning by expressing that the aggregator manages the flexibility of consumers and trades it in organized markets and via bilateral contracts. It is argued that the aggregator acts as a gateway for residential demand response to the wholesale market. Conversely, Ikäheimo et al. (2010) define the aggregator with a broader scope, not solely focusing on demand response, but recognizing flexibility from a range of distributed energy resources (DER) at the end user, including demand response, energy storages and distributed generation. Ikäheimo et al. (2010, p. 10) define the aggregator as: *"a company who acts as an intermediary between electricity end-users and DER owners and the power system participants who wish to serve these end-users or exploit the services provided by these DERs".*

Various other organizations have also attempted to define the concept of aggregator. One of these organization is the USEF Foundation, which resulted from a collaboration between key players in the smart energy domain.

The USEF Foundation is very active in developing an integral market design related to flexibility. USEF is a framework that describes a market model for trading flexibility, this includes a description of the architecture, tools, rules and the interaction among the involved actors (USEF Foundation, 2015a). The USEF Foundations argues that for prosumers to gain access to flexibility markets, which is according to them necessary for the long-term sustainability of the energy system, a new role is needed in the electricity market. This new role is the aggregator and it is centrally positioned in the USEF model. USEF describes the aggregator not so much as a market party but defines it as a new role in the market design. They define the role of aggregator as: *"to accumulate flexibility from prosumers and their active demand & supply and sell it to the BRP, the DSO, or (through the BRP) to the TSO."* (USEF Foundation, 2015a, p. 20). The USEF Foundations argues that this role of aggregator can be fulfilled by both existing market parties (e.g. suppliers) and new entrants (USEF Foundation, 2017). This results from their definition of aggregator, as they specify the aggregator as a role and not as a market party. The role of aggregator can be combined by a market party that also fulfils other role(s), like supplier and BRP. However, they leave it up to the existing and new market parties, if they want to fulfil only the role of aggregator or combine several roles. The USEF Foundation is in favour for market facilitation of independent or third-party aggregators (USEF Foundation, 2015b). The independent element means that it is not linked to the supplier or BRP that serves the customer.

5.2.2 Policy makers

The regulatory framework is very important for defining aggregators, as it gives legal boundaries to aggregators in the European Union. This includes both national legislation and regulation constructed by the institutions of the European Union (i.e. European Commission, Parliament and Council). Therefore, both the position of the institutions of the European Union institutions and the Dutch government are being described.

Institutions of the European Union

The Energy Efficiency Directive (2012/27/EU) was the first European legislative document that described the aggregator. The main objective of this Directive is to establish a binding set of measures that ensure the EU reach its 20 % energy efficiency target (European Parliament, 2012). One of the described instruments for improving energy efficiency is demand response. It is argued that demand response could lead consumers to take actions on consumption and to reduce or shift consumption. However, it is heavily debated if demand response has an effect on reducing the energy consumption, as proposed in the Directive (Kim & Shcherbakova, 2011; Palensky & Dietrich, 2011; Warren, 2014). Still, the Directive describes aggregators in the context of demand response as enablers for flexibility. The Directive states that: *"aggregator means a demand service provider that combines multiple short-duration consumer loads for sale or auction in organised energy markets"* (European Parliament, 2012, p. 12). This definition describes aggregators as demand service providers. Unfortunately, no clear definition is given about the meaning of what demand services are. The aggregator is described in the context of demand response. Therefore, demand response is most like to be a form of demand service. The definition also indicates a time dimension of the service, namely: multiple short-duration consumer loads. Finally, aggregators are characterized as entities that sell or auction their service in an energy market. This implies that aggregators are in principle actors that are involved in the trading of electricity.

The European Commission has also defined the aggregator in their new legislative package, the Clean Energy for All Europeans Package (COM (2016) 864). In this legislative package, which contains a revision of the Electricity Directive, the definition of aggregators is made in the broader context of giving customers (industrial, commercial and households) access to the energy markets to trade their flexibility and self-consumed electricity. Hence, the aggregator concept is defined as: *"a market participant that combines multiple customer loads or generated electricity for sale, for purchase or auction in any organised energy market"* (European Parliament and the Council, 2017, p. 53). There are some differences in this definition compared to how aggregators are defined in the Energy Efficiency Directive (2012/27/EU). First of all, aggregators are not anymore defined as only "demand service providers", the new proposal for the Directive defines aggregators much broader as "market participants". Secondly, this proposed revision of the Electricity Directive includes also generation in its definition. Therefore, the definition of the concept aggregator has shifted in recent years in EU legislation. The concept of aggregator has been broadened by not only focusing on demand services and loads but expand it by including generation and define it as a market participant.

Dutch Ministry of Economic Affairs and Climate

The Dutch Ministry of Economic Affairs has developed a roadmap with upcoming developments in energy policy, the Energieagenda (Ministerie van Economische Zaken, 2016a). This document presents the interventions that are necessary for energy policy to decarbonize the energy system.

In this document, it is recognized that a new market role, the aggregator, is necessary to unlock flexibility at consumers in the retail market (Ministerie van Economische Zaken, 2016a). The aggregator is perceived as a market party that unburdens the consumer or producer by cleverly trading their consumption, production or flexible capacity. It is argued that this aggregator can be both active in unlocking flexibility at large scale (industrial) consumers and both at small scale consumers like households. However, aggregators are claimed for being essential in unlocking substantial amounts of flexibility from small-scale users.

5.2.3 Electricity market players

Several actors that are active in the Dutch electricity system have also expressed their definition of the aggregator concept. Several of these expressions are being described in the following paragraphs.

Grid operators

Both the transmission grid operator, TenneT, and the regional distribution grid operators (DSO) are actively involved in the debate concerning aggregators.

The DSOs Alliander and Enexis have been involved in several projects where they defined actors as aggregator. These projects consist of pilots where innovative concepts on trade, market design and technology where practiced.

Enexis has been active with the 'Jouw Energie Moment' project for several years (Senfal, Enexis, TNO, Technolution, Shifft, 2017). In this project, the aggregator has an important role. The aggregator was defined as the party that provides control signals to assets at end-users to make sure that they make optimally use of electricity by shifting demand to times with lower electricity prices. Therefore, the aggregator is mainly described as a party that controls assets cleverly and pools these assets. Interestingly, as was also raised in an interview with Enexis, the aggregator is not necessarily involved in the trade of electricity. The aggregator could be a party that is only involved in controlling assets and aggregate these assets.

Alliander is active in the USEF Foundation and is implementing the USEF insights in pilots in the DYNAMO project (Liander, 2018). In this project, a similar definition of aggregators is being used as described in the USEF Framework. Aggregators buy flexibility at end-users (households, SMEs, large consumers) and can control consumption to realize flexibility. The aggregator than trades this flexibility at electricity markets. Alliander is one of the flexibility buyers in this pilot, by using flexibility to prevent overloading of the medium/low voltage grid. Therefore, the aggregator is perceived as an intermediary, a party that unlocks flexibility at end-users and sells this flexibility to (multiple) parties.

Incumbent utilities

Several of the incumbent utilities in the Netherlands have been active with the aggregator concept and elaborated on their definition of an aggregator.

The utility Eneco is active in the field of aggregators with propositions like AgroEnergy, Jedlix, CrowdNett and Peeeks. These propositions focus on a specific customer segment or technology. New business models are implemented to gain experience with the aggregation of multiple flexible loads into a pool. AgroEnergy, specialized in assisting customers in the horticulture sector, elaborates on the concept of the aggregator in a whitepaper (AgroEnergy, 2017). They define the aggregator as an entity that accumulates flexible capacity (aggregation) and brings this to an electricity market. Secondly, it is recognized that the aggregator is also involved in controlling assets remotely. In an interview and research report about CrowdNett this is endorsed (Brouwer, 2018). That the aggregator is an intermediary between end-users and electricity market players, by combining multiple small assets/loads into one position.

Essent is another large Dutch utility which is active in the field of aggregators. Essent has participated together with Alliander in a pilot project called EnergieKoplopers (EnergieKoplopers, 2016). Essent acted as aggregator and defined this as an intermediary between supply and demand of flexibility, that unlocks flexibility and offers this to electricity market players (including the DSO). This project uses the USEF framework and therefore the aggregator definition is in line with the framework. Powerhouse, a separate company but part of Essent, described also in an interview the aggregator as an entity that pools flexible resources (both at consumption and generation side) and offers this to parties that are demanding this flexibility.

Aggregators

Various aggregators are active in the Dutch electricity market and their description of an aggregator differs considerably. This could be partially explained by the fact that these companies identify themselves with the concept of an aggregator and therefore describe an aggregator based on their own business model.

Controlling assets to unlock flexibility is often raised in describing aggregators. However, not all aggregators are explicitly stating that aggregators should accumulate different assets into a pool to sell this accumulated flexibility on the electricity market. Several aggregators, like Senfal and EXE, have products that focus on decentral optimization, so assets can adjust their consumption and production based on (real-time) electricity prices. This means that flexibility is not necessarily pooled and traded as a single bundle of flexibility, but that flexibility could also be monetized decentrally by local optimization.

5.3 Comparison of aggregator descriptions

As the aggregator concept is not well established, yet the concept holds ambiguity. However, several conclusions can be drawn from the above-observed definitions and descriptions of the aggregator concept.

Firstly, the debate highlights that aggregators can be both seen as a (new) market intermediary, an actor or market party, and as a role. The difference is that a market intermediary is an actor that represents a party that is involved in a transaction (ENTSOE, 2017). While the role represents the external intended behaviour of a party, the interactions with other parties in relation to the goal of a transaction (ENTSOE, 2017). Therefore, an actor takes up a specific role or a set of rules and the role(s) represent the function, responsibilities, etc of that actor. It is important to make this distinction, as a role represents the external intended behaviour and therefore some entity should define this. Therefore, roles are often defined in legislation like EU regulations, national laws and network codes. Conversely, actors are free to choose which role(s) they play and/or if they identify themselves with that role. Interviewees underlined this crucial difference and opinions differ as of an aggregator is a role or solely an actor.

Secondly, controlling assets is mentioned by many in relation with aggregators. Controlling assets results in unlocking flexibility, as the consumption or production is adjusted according to some condition. Nevertheless, the trade of this flexibility in marketplaces is not mentioned by everyone as an essential element in the aggregator concept. Trading of flexibility means involvement in the trade of electricity at electricity markets at its own risk. However, the aggregator could also be solely involved in accumulating flexibility and not trade this electricity. Aggregating flexibility could contain a trading component or act as a conduit for only controlling assets.

Thirdly, the concept aggregator originates from the word aggregation. Hence, this implies that aggregating multiple flexible sources into one pool (i.e. aggregation) is an essential element of the aggregator concept. Aggregators may next to bundling many small flexibility resources, also provide services to make it possible that certain resources become flexible (Hers et al., 2016). For example by providing smart software and/or hardware to control the charging of EVs in such a matter that it results in flexibility. Therefore, the aggregator can also unburden the consumer, producer or prosumer by cleverly trading and (possibly) control their consumption, production or flexible capacity. It could be questioned whether this is still aggregation, as it is locally optimizing consumption and/or production to unlock flexibility. Notwithstanding that companies involved in these activities need to develop resources and competencies to facilities this decentral optimization (e.g. software platform, hardware development). Hence, it could be argued that there is a pooling of customers that assist the company in its operations.

Fourthly, there is a whole debate if the aggregator should be considered independent. Independent means not linked to the supplier or BRP of the customer. As some argue that a level playing field is necessary to unlock the full flexibility potential and thus enable aggregators dissociated from the supplier or BRP.

Lastly, the descriptions of aggregators differ in the scope of flexibility. Flexibility is both present at the demand side (e.g. peak shifting) and supply side (e.g. curtailment). However, some descriptions focus primarily on demand response at the consumption side and do not include potential flexibility at the generation side. Several other descriptions have defined the aggregator as being active with distributed energy resources (RES), including generation flexibility. It is important to recognize that aggregators can be involved in more than only demand response in the form like peak shifting, but also at flexibility in generation like curtailment of solar or wind power.

5.4 Typology of aggregators

The above described literature review shows that the aggregator concept is a concept that contains many different elements. A typology of aggregators is constructed to illustrate the differences that the aggregator concept holds. This typology is constructed with the use of the above described literature review and is partially based on the framework of the USEF Foundation (2015). The EU funded research study on business models of aggregators, BestRes and a policy paper by ENTSO-E are also being used as input for this typology. (ENTSO-E, 2015; Verhaegen & Dierckxsens, 2016). The aggregator concept is not yet fully established in the Dutch electricity market and is still materializing. Therefore, this typology is being introduced to clarify the characteristics that aggregators hold, how they interact within the electricity market design and how their business models are constructed.

The following sections describe the different aggregator types and introduce the core aspects of each aggregator type. A schematic diagram of each aggregator types is presented to highlight the important actors and actor relationships. Arrows in these diagrams represent actor relationships. This aggregator typology will be used throughout the rest of this report and other parts of this report will go into further detail on specific topics concerned with the different types.

5.4.1 Combined aggregator-supplier

The first type of aggregator is the combined aggregator-supplier. In this model, the aggregator provides an integrated proposition to the prosumer. This proposition includes both options to use the flexibility and the supply of electricity to the prosumer.

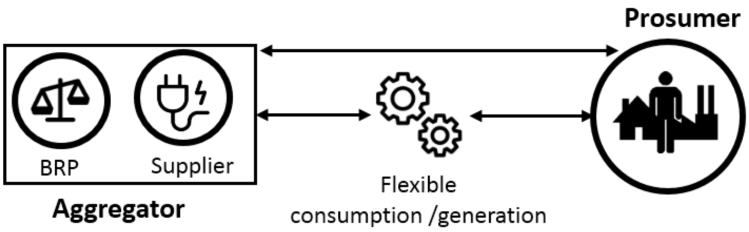

Figure 9 Combined aggregator-supplier

Supply and commercialisation flexibility are offered as a package by one market party. The aggregator fulfils both the roles of BRP and supplier. Thus, there will only be one BRP that is associated with the prosumer. Activation of flexibility and its impact on the E-program will only impact the aggregator, as it is also BRP. Compensation to other parties for things like sourced electricity is not necessary, as the aggregator has also the role of supplier.

Thus, the aggregator is a one-stop shop, that fulfils the roles of BRP, supplier and monetizes flexibility for the prosumer. Hence, the aggregator provides an integrated proposition to the prosumer.

5.4.2 Combined aggregator-BRP

The second type of aggregator is the combined aggregator-BRP. In this case, the aggregator combines his role of aggregator with that of BRP. The prosumer has a contract with a supplier for the sourcing of electricity. Additionally, the prosumer has an agreement with a separate party, the aggregator, for the commercialisation of its flexibility.

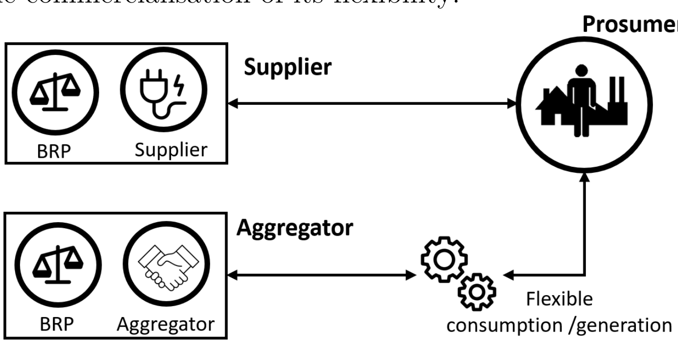

Figure 10 Combined aggregator-BRP

This results in two BRPs on the same connection. Hence, the supplier has its BRP and the aggregator has its BRP as well. Arrangements need to be made between the aggregator and supplier, as the aggregator may use electricity sourced by the supplier and the aggregator could influence the imbalance position of the supplier's BRP. The aggregator sells the flexibility at its own risk on behalf of the prosumer.

Additionally, this situation could be present when a virtual transfer point is created. This implies that a contract between aggregator and supplier may not be necessary, as next to the main metering point a virtual transfer point is created with metering.

5.4.3 Aggregator as service provider

An aggregator can also act purely as a service provider by only providing the means to access flexibility and not selling it at his own risk. The aggregator provides the means to access flexibility and offers this access as a service to other parties. This access to flexibility can be achieved by for example a software platform that is able to control decentral assets.

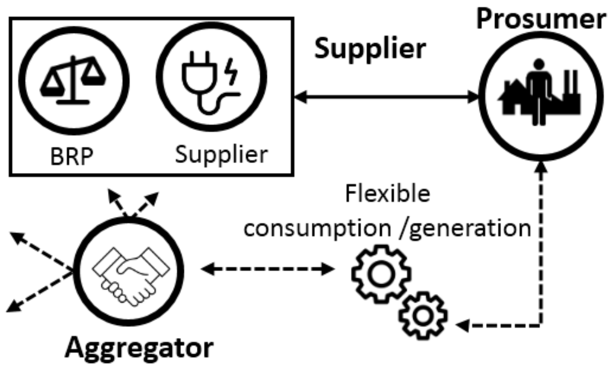

Figure 11 Aggregator as a service provider

The aggregator as service provider does not take the role of BRP or supplier. The aggregator could be perceived as not active in the traditional electricity value chain. Flexibility is not sold, but a service is created that allows other market parties to unlock and use flexibility at prosumers. Thus, this type of aggregator does not trade flexibility but solely collects flexibility from prosumers and organizes this as a service.

5.4.4 Delegated or Broker Aggregator

The delegated aggregator sources flexibility from prosumers and sells this at its own risk to other market parties or marketplaces. This type of aggregator does not take up the role of BRP or supplier. This means that there is only one BRP, which is the BRP of the supplier at the connection of the prosumer.

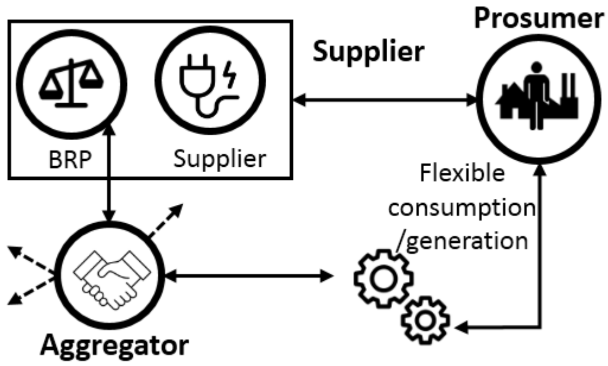

Figure 12 Delegated or broker aggregator

Since the aggregator is not a BRP, it needs to have an arrangement with BRP at the connection of the prosumer. Procedures need to be in place how to cope with the activation of flexibility by the aggregator. This activation has an impact on the position of the BRP.

5.4.5 Prosumer as Aggregator

Prosumers could choose to adopt the role of aggregator. They could aggregate a portfolio of flexible assets that they own. This portfolio could then be traded with other market players or at marketplaces.

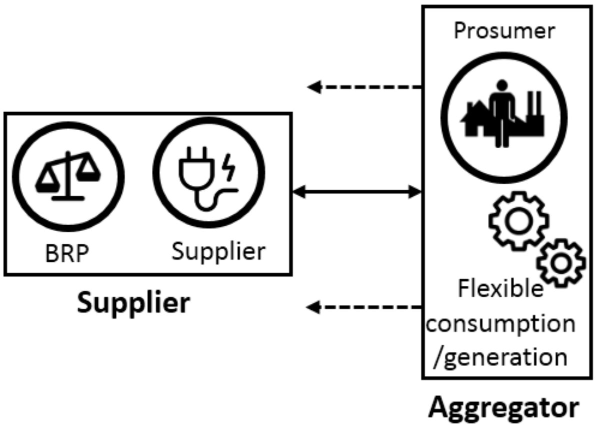

Figure 13 Prosumer as Aggregator

The prosumer as aggregator is not involved in the role of supplier or BRP but only aggregates flexibility from its own resources. For large-scale prosumers it would be more convenient to adopt this aggregator type as the volume of flexibility is more likely to be present to aggregate into a pool.

5.4.6 DSO as Aggregator

The DSO can also act as aggregator which results in the DSO as aggregator model. This model is very similar to the delegated/broker aggregator. Hence, the aggregator is in this model the DSO and uses flexibility for the purpose of congestion management.

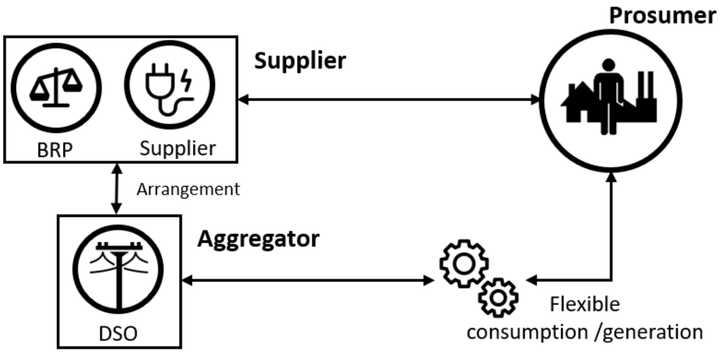

Figure 14 DSO as Aggregator

The DSO as aggregator is not BRP or supplier and is only involved with the flexibility from the prosumer. An arrangement needs to be in place between the DSO as aggregator and the supplier/BRP. Activation of flexibility by the DSO as aggregator will influence the supplier/BRP and procedures need to be in place to cope with the results of this activation.

5.4.7 Overview of aggregator typology

The aggregator typology contains a classification of six aggregator types. Three types represent an aggregator with a combined role, the combined aggregator-supplier, the combined aggregator-BRP and the DSO as aggregator. The three other types non-combined aggregators. These non-combined aggregators focus solely on flexibility. A visual overview of the aggregator typology is presented below

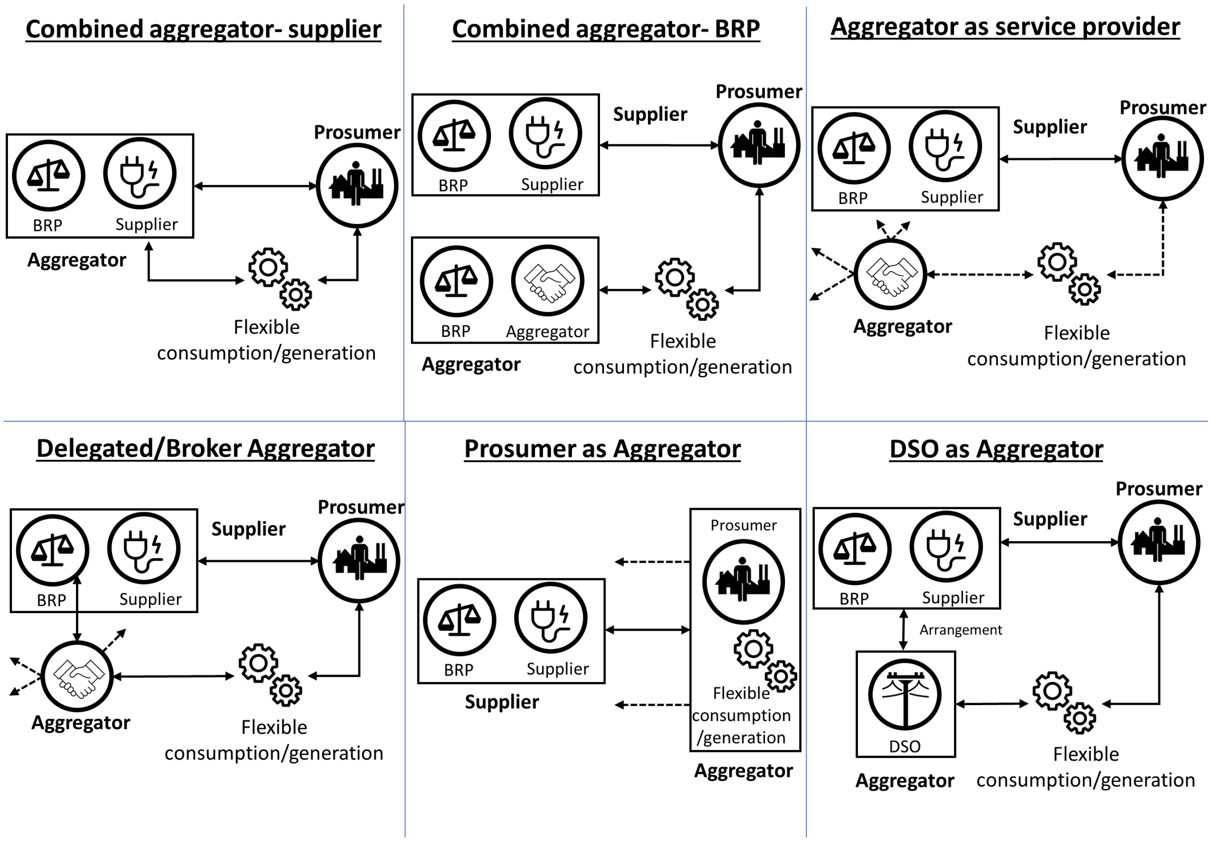

Figure 15 Overview of aggregator typology

Chapter 6

Market facilitation of the aggregator

The electricity market design structures the electricity system and sets out market rules and responsibilities. In this chapter, the characteristics of the current electricity market will be examined in relation to the aggregator concept. This analysis leads to insights of the market facilitation of aggregators, which assisted in answering the third sub-question: *How is the current Dutch electricity market facilitating aggregators?*

6.1 Aggregator typology and market facilitation

The constructed typology, as described in chapter 5, explains the main principles of the different aggregator types. In this section, the aggregator typology is used in analysing how the different aggregator types are supported within the current market design. The following paragraphs describe the market facilitation of each of the different aggregator types.

6.1.1 Combined Aggregator-Supplier

The combined aggregator-supplier model specifies that the aggregator provides a proposition for flexibility but is also acts as a BRP and supplier. In the current electricity market design there is made no distinction between suppliers that provide flexibility options in their proposition compared to suppliers that are not including this. Suppliers have the freedom to develop their own proposition to customers, regardless of whether this includes flexibility options or not. Therefore, in relation to the market design, the aggregator is a supplier of electricity and BRP that includes flexibility options in its contract with its customer.

Obligations of supplier

In the Dutch electricity market design, there are different rules and regulations that apply to suppliers that supply electricity to small or large consumers. The Electricity law of 1998 defines small consumers as consumers that have a maximum capacity of 3*80A at their connection (Rijksoverheid, 1998). Consumers that have a larger capacity at their connection are defined as large consumers. The distinction between small and large consumers has been made to provide consumer protection to small consumers. Companies that supply electricity to small consumers are retailers that need to have a permit to operate and need to follow several rules and regulations. In contrary to retailers for small consumers, suppliers to large consumers have fewer regulations in place and do not need a permit.

This distinction between small and large consumers influences the market facilitation of aggregators. Making a proposition for large consumers, as a combined aggregator-supplier, is less complicated than supplying small consumers with this proposition. There is a lot more contractual freedom in supplying a large consumer compared to a small consumer. The compulsory licensing of retailers to small consumers and related consumer protection regulations require more effort from retailers that supply small consumers. However, these differences in contractual freedom and obligations are not exclusively in place for aggregators. The electricity supply sector is managing these differences already since 1998 (Rijksoverheid, 1998). Mulder and Willems (2016) assessed ten years of experiences in the Dutch retail electricity markets and concluded that the retail market matured and is competitive. They observed strong product innovation and the integrated proposition of the combined aggregator-supplier could be an example of such a product innovation.

Balance Responsible Party (BRP) obligations

The combined aggregator-supplier model describes the aggregator adopting the balance responsible party (BRP) role. The BRP, as described in appendix A, is the responsible party for imbalances and the associated cost. The BRP submits one day before actual delivery the E-program for every ISP of that day to the TSO. The combined aggregator-supplier is using the flexibility that the prosumer has. The activation of flexibility can contradict the schedule that is provided in the E-program. Therefore, financial transactions may result from this flexibility activation. The aggregator will be responsible for these financial transactions, as the combined aggregator-supplier is also BRP.

The Dutch electricity market is organized in such a way that everyone is entitled to become a BRP. However, regulations have been put in place that describes how to become a BRP and the associated operational procedures (ACM, 2015b). The TSO, TenneT has the authority to provide licenses to parties that request to be a BRP. Pont-van Bommel and Buist (2014) argue that several hurdles exist in becoming a BRP as.

First, a financial guarantee in the form a bank guarantee needs to be present. This bank guarantee needs to cover at least 96.000 euro, the actual amount depends on the transaction volume of BRP (Pont-van Bommel & Buist, 2014). The bank guarantee provides TenneT to some extent security that the charged fees for imbalances can be retrieved. Secondly, the risk of financial liability due to costs associated with imbalance can be perceived as an entry barrier. Thirdly, a data connection with TenneT and a software system is necessary to communicate E-programs, invoices and information about imbalances. Two interviewees argued that they perceived the necessary investments associated with setting up such a software system as a barrier. One interviewee indicated that developing such a software system requires investments in the order of hundreds of thousands of euro.

The Dutch Electricity law states that the electricity supplier of small consumers is responsible to organize the balance responsibility for the connection of a small consumer (Rijksoverheid, 1998). Suppliers can act autonomously as a BRP and integrate this activity into the entity of the combined aggregator-supplier. However, several BRPs provide BRP-as-a-service products (e.g EDMij, PVNED). This means that a supplier appoints another party as BRP for its portfolio. These parties then fulfil the BRP role for these retailers. This is a common practice in the electricity supply industry and is a possibility for combined aggregator-suppliers.

The currently being implemented Electricity Balancing Guidelines (EBGL) introduces the balancing service provider (BSP) role (TenneT, 2017a). This new role is introduced to separate the balance responsibilities from the provision of balancing services. The BSP role describes exclusively the activities of providing balancing services to the TSO. This new BSP role makes it possible for market parties to participate in balancing services without adopting the BRP role.

Complexity in market design

The complexity of the combined aggregator-supplier model in the market design is relatively low. The market rules for suppliers/retailers do not hamper parties to include flexibility options in their proposition. The proposition itself does not contain a lot of contractual complexity, as the combined aggregator-supplier integrates flexibility in the contract for the supply of electricity. A single party interacts with the customer and therefore only one contract with the customer is necessary.

6.1.2 Combined Aggregator-BRP

The combined aggregator-BRP model describes that the supplier is separated from the aggregator. Multiple parties interact with the customer and two BRPs are active on the connection of the customer. Arrangements need to be in place to manage the interactions between the involved market parties and the customer.

MLOEA (Meerdere leveranciers op een aansluiting)

One of the arrangements that facilitate the combined aggregator-BRP model is the MLOEA (multiple suppliers at a single connection) regulation. This regulation describes the market rules for having multiple suppliers active at the same connection (ACM, 2017a).

The MLOEA regulation facilitates the combined aggregator-model by making two or more separate transfer points of electricity. A transfer point ('allocatiepunt' in Dutch) is defined as the location where the transfer of energy between the local installation (e.g. house) and the grid is administratively assigned to a market party (ACM, 2017a). Each transfer point has a smart meter and an assigned identification number (EAN code) that registers the power flows. Furthermore, for every transfer point balance responsibility is arranged separately. Thus, at every transfer point there is a BRP with separated balance responsibility between the different transfer points. Figure 16 represents the two architectures that are allowed by the MLOEA regulation and facilitate the separate transfer points, namely a serial and parallel option.

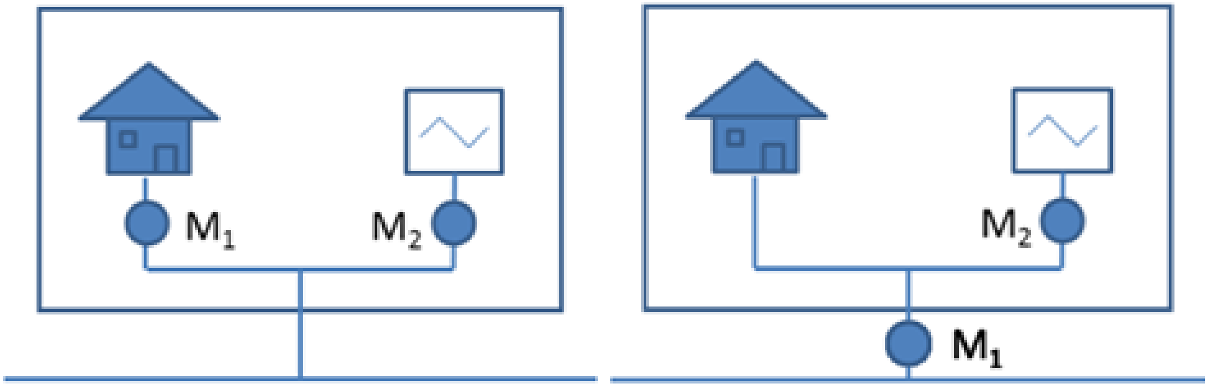

Figure 16 Diagram of connection with parallel (left) and serial (right) metering. M1 and M2 represent the two transfer points with the metering devices (ACM, 2016).

The parallel option (left) is most applicable to small consumers like households (ACM, 2016). These connections are directly connected to the grid and a second parallel transfer point can easily be created. At this second parallel transfer point, there is an independent second meter and each separate meter registers power flows and has an assigned BRP.

Serial metering, as displayed on the right of figure 16, is most appropriate for large consumers (ACM, 2016). The meter at the main transfer point (M1) is often expensive as the connection of large consumers (>3*80A) includes power/voltage transformers and metering equipment is more expensive. Therefore, a serial transfer point can be created by placing a second meter close to its connected installation. Both metering/transfer points record the power flows and have assigned BRPs. Administrative this serial metering architecture is more complex. Electricity that is consumed or produced at the second transfer point (M2) could also flow through the first transfer point (M1). Therefore, the metering data at the first transfer point (M1) is corrected by subtracting the power flows that went to the second transfer point (M2).

The MLOEA arrangement has been created to make it possible for consumers to have multiple electricity suppliers. The diagram of the combined-aggregator BRP model, as visualized in figure 10, indicates the combined aggregator-BRP not fulfilling a supplier role. Nevertheless, the MLOEA arrangement facilitates that multiple market parties can be active on the same connection, regardless of calling it a supplier or not. Therefore, this arrangement works in practice also to support the combined aggregator-BRP model as balance responsibility is clearly separated and defined.

The MLOEA regulation makes sure that the responsibilities for the BRPs are clearly defined. Each BRP is responsible for the electricity that flows through its own transfer point and this is allocated with the metering data. Therefore, no further arrangements need be made between the BRPs about how to distribute the effects of imbalance.

Contractual freedom in organizing commercial arrangements
The arrangements that are present in the MLOEA regulation demonstrate how the structure and the relations between parties can be organized. Market parties and consumers are regulated but are still able to construct arrangements among themselves in organizing this type of aggregator. Market parties have the contractual freedom in organizing redistribution of benefits or costs. Market parties have the possibility to construct contracts and conditions among each other that make it possible to act in a structure like the combined aggregator-BRP model. However, contracts should be constructed in such a way that responsibilities and financial compensation or consequences are clearly defined.

Complexity in market design
The degree of complexity in the combined aggregator-BRP model is somewhat higher than the combined aggregator-supplier. This has to do with the increase in the number of market parties involved at the connection and the arrangements that need to be in place in organizing this structure. Contractual complexity can be high if all arrangements will be created in the commercial domain without using mechanisms like MLOEA, as the conditions and responsibilities of many elements should be defined. The MLOEA regulation simplifies thing by having clearly defined responsibilities and obligations.

6.1.3 Aggregator as Service Provider

The aggregator as a service provider is not adopting a formal role that is currently present in the electricity market design. This type of aggregator is not selling electricity or flexibility at its own risk. Currently, the electricity market design is mainly focussed on the trade of the electricity as a commodity. Therefore, the electricity market design has no specific market rules for aggregators that act as a service provider.

The integration of decentralized assets and involvement of prosumers in the electricity system request for adjustments in markets and the market design, as Parag and Sovacool (2016) state in their "Electricity market design for the prosumer era" article. New services arise in markets where prosumers are active. The aggregator as a service provider is an example of such a service. The aggregator as a service provider is not active in the traditional value chain of selling electricity. The aggregator as service provider is providing a service to other market parties. Flexibility is unlocked by the aggregator and access to this flexibility is provided as a service.

No major hurdles exist in the current electricity market design for market parties to act as an aggregator, because the aggregator as a service provider is currently not defined as a role in the electricity market.

6.1.4 Delegated/Broker Aggregator

The main characteristic of the delegated aggregator is that it is not a BRP. The delegated aggregator has an arrangement with the (incumbent) BRP that is active on the connection of the customer. Arrangements should be made about how to deal with activation of flexibility. These arrangements are mainly within the commercial domain, as agreements are made between market parties. The electricity market design includes freedom of contracts, so market parties are free to determine the content and conditions of an agreement. However, some complexity comes into play as the delegated aggregator needs, besides having an arrangement with the BRP, also needs to make arrangements with the customer that it serves.

BRP imbalance effects

One of the key elements that should be included in the arrangements that the delegated aggregator makes is how to deal with the settlement and distribution of imbalances and the related financial consequences.

The mFRR ('noodvermogen') product of TenneT is an example of how the current market design is facilitating settlement and distribution of effects with delegated aggregators. The activation of mFRR by the delegated aggregator is influencing the imbalance position of the BRP. TenneT assists in the settlement process of correcting this influence. This is done by correcting the imbalance position of the BRP that is affected by the activation of mFRR. This means that TenneT acts as an intermediary in arranging the administrative correction of the imbalance.

The correction of imbalance in the case of mFRR is done with a product of TenneT. When market parties want to organize this in the commercial domain (i.e. not an ancillary service product) then they need to organize this by themselves. Conditions and contracts need to be constructed that will assist in redistributing financial consequences of activation of flexibility. Market parties indicated during interviews that complex service level agreements (SLA) need to be drafted that contained the necessary provisions to organize this delegated aggregator. Constructing such an SLA can be time consuming as many details need to be negotiated. Currently, no standard model contracts are available. An interview participant indicated that the presence of such a standard agreement could potentially speed up the process of arranging the contracts as many details are already being investigated for such a model contract.

Contracts with the flexibility side

The delegated aggregator is using the flexibility of the prosumer. The prosumer has a contract with its supplier but there should also be a contract between the delegated aggregator and the prosumer, as the prosumer is probably receiving financial compensation for the use of its flexibility. Therefore, the prosumer will have contracts with its supplier and with the delegated aggregator. However, the conditions of both these contracts should be aligned with each other, to make sure that one is not infringing the other. In the current market design, there are no rules that assist in this, which leaves this to the responsibility of the market parties and prosumer. It is currently unclear who is responsible for checking this.

Laws and regulations are in place to ensure consumer are appropriately protected in the energy markets. Suppliers of electricity needs to obey these rules. It is unclear if these same rules should and will apply to aggregators. Aggregators can create contractual constructions to avoid that supplier laws will apply to them. For example, the delegated aggregator could use the supplier for the contractual arrangements with the prosumer (e.g. let the payment go through the supplier to the prosumer).

6.1.5 Prosumer as Aggregator

It is more likely that large consumers will act as a prosumer as aggregator than small consumers. This has mostly to do with the volume of electricity usage/production and the number of assets that large consumers operate.

The supply of electricity and therefore also the trade of flexibility by a prosumer as aggregator, is less strictly regulated for large consumers than that for small consumers. Less consumer protection regulations are in force for the supply of large consumers and it is not necessary to obtain a supply license in case of supply to large consumers (ACM, 2015b). This supports the prosumer as aggregator model for large consumers, as it eases processes for prosumer as aggregator to take control of its own flexibility and to operate it.

The prosumer as aggregator builds a portfolio of assets that are flexible and tries to trade this flexibility. However, the prosumer as aggregator has still a contractual relationship with a supplier and BRP. Therefore, the contracts between the prosumer as aggregator, the supplier and the BRP should allow the prosumer to act as an aggregator. This can lead to new negotiations between parties to legitimatise the prosumer to act as an aggregator. Moreover, this can lead to a time-consuming process to construct new complex arrangements. A model or standard contract could assist this process, but situations are often case-specific.

6.1.6 DSO as Aggregator

DSOs are on a quest to cope with increasing loads on their grid and to prevent congestion. The Dutch grid operators would like to use flexibility in some cases as alternative for grid reinforcements (Bokhoven et al., 2015). It is important to note that developing flexibility and the aggregator concept are not an end in itself. Flexibility is a means to deliver a more affordable, secure and efficient electricity system (CEER, 2018). Flexibility can be used by DSOs to alleviate insufficient transfer capacity in the network by active congestion management. The development of aggregator concept is subsequently a means to unlock this flexibility.

Recently much discussion has been taking place on the role and possible additional activities of DSOs. DSOs acting as an aggregator is such new activity. Regulators have recently published their stance in this discussion.

The Council of European Energy Regulators (CEER), an organization where Europe's national energy regulators work together, has recently published a report that presents the position of the CEER on flexibility in relation to the DSO (CEER, 2018). The benefits of using flexibility by DSOs are recognized by the CEER, for example by using it for congestion management. They argue that DSOs should be able to access flexibility. However, it is also argued that it is essential that the DSO acts as a neutral market facilitator and that it will not unduly distort markets or competition. Consequently, CEER argues that flexibility products should be developed in markets and the DSO would be the user of flexibility. The unbundling of generation and distribution is highlighted by the CEER. Thus the DSO may be the user of flexibility but can not act as the provider of flexibility, which is an activity within the commercial domain.

This statement of the CEER does not provide clarity about the legality of DSOs directly in contact with the prosumer to aggregate flexibility for the purpose of congestion management. However, the Dutch energy regulator ACM has also published their position about DSOs acting as aggregator.

The ACM provides its view on which new activities may be adopted by the DSOs, that result from the new law called the law VET ('Voortgang energietransitie') (ACM, 2017c). The ACM provides a more detailed explanation of the legality of the DSO as aggregator. They argue that flexibility services that an aggregator provides are fundamentally related to some kind of trade of electricity. The ACM defines flexibility as changing consumption or production of electricity at a certain moment in time, thus service related to flexibility involves the trade of electricity. The Electricity law of 1998 prohibits DSOs is in the Netherlands to participate in the trade of electricity and therefore it would not be allowed for a DSO to act as an aggregator. The ACM argues that flexibility at the DSO level (i.e. congestion management) should be sourced with a market-based approach where the DSO itself will not act as an aggregator (ACM, 2017c).

To conclude, the current regulatory framework is not supportive in facilitating DSOs to act as aggregator. Current legislation provides a delineated description of the tasks and obligations of the DSO, as set out in the Electricity law of 1998 and the law VET. The description of tasks of the DSO does not include any activities related to the DSO as aggregator.

6.2 Market facilitation assessment by market parties

As stated in chapter 2, data have been collected from interview participants about their opinion on how the market facilitates the different aggregator types. Participants were asked to rank the aggregator types according to how good the current market design is facilitating these types. Figure 17 presents an overview of the results of this ranking.

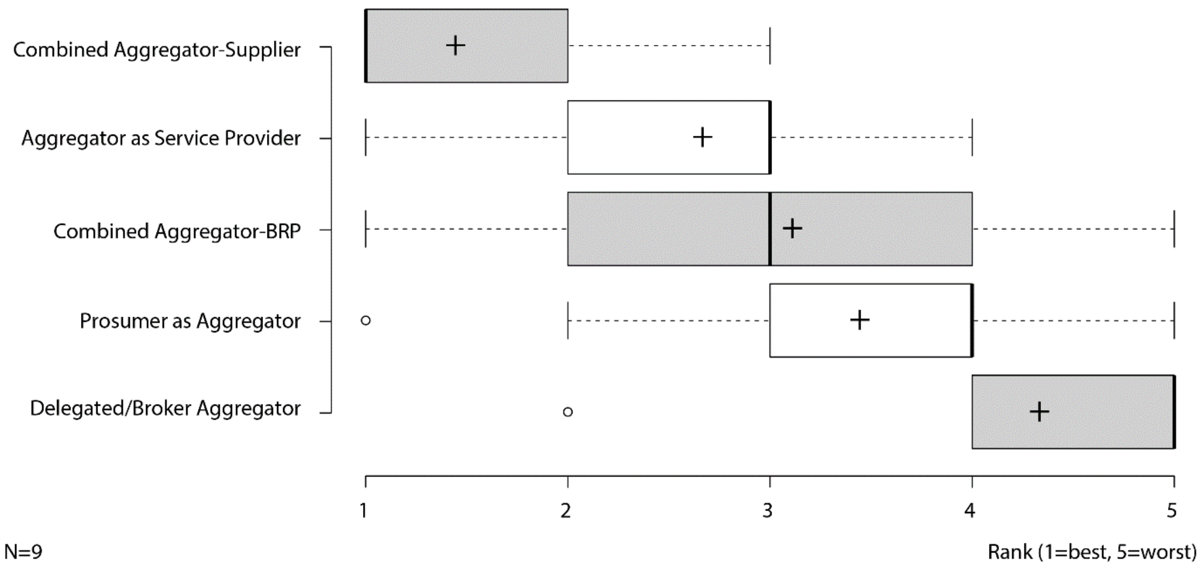

Figure 17 Boxplot diagram of the market facilitation ranking of the different aggregator types. Ranked from 1 to 5, with 1 being the best facilitated and 5 the worst.

The majority of participants assessed the combined aggregator-supplier as best facilitated within the current market design. Four interviewees argued that this kind of aggregator is close related to activities that market parties have traditionally done in the electricity market. Therefore, it is relatively easy for (traditional) suppliers to integrate an extra activity in its proposition. Furthermore, the regulatory framework for this type of aggregator is very similar to the rules and regulations that apply to suppliers. This assists the transparency for new entrants, to which rules and obligations apply or are expected from them.

The aggregator as service provider type has also been identified by many as well supported within the current market design. The element of not actively trade electricity is highlighted by some as important in their ranking. Not being active in trading electricity results in the easing of regulatory pressure, fewer market rules may be relevant for them.

Discussions about assessing the market facilitation of the combined aggregator-BRP type were often lengthy and contradictory. This is also visible in the data and in figure 17, as the variation is large. Two interviewees argued that arrangements like the MLOEA regulation facilitate this type of aggregator. Whereas others argue that this type of aggregator is nearly impossible due to the complexity of having multiple BRPs at the same connection. It is evident that the complexity of this type of aggregator influences the results of the ranking and that ambiguity is present, to what degree the current market design is facilitating this kind of aggregator.

The complexity of the electricity market has been described by several interviewees as a reason why the prosumer as aggregator is not well supported in the market design. Entry barriers were described, but most described the lack of expertise by prosumers as the main reason of ranking this type as low in market design support. The market design is based on a considerable amount of market rules, regulations, laws etc. Knowledge about these rules and market procedures is essential to operate in the market. Prosumers often lack this knowledge according to several interviewees, which make prosumers reluctant to use flexibility in the form of prosumer as aggregator.

The delegated/broker aggregator was predominantly considered as not well supported within the current market design. Several arguments for this were given. First, the complexity (e.g. transfer of energy) of the agreement between the aggregator and BRPs makes this type difficult to function. Secondly, the aggregator may need contracts with a multitude of BRPs, as many different BRPs operate within the Netherlands. Lastly, the activation of flexibility impacts the imbalance position of the BRP and therefore the BRPs may be reluctant in cooperating with the delegated aggregator as it can be perceived as disturbing regular BRP operations.

The DSO as aggregator is not included in the ranking as this type was identified and added to the typology in a later phase of research when multiple interviews were already completed. Therefore, it was decided to not include this type in the ranking to ensure that all participants ranked the same set of aggregator types.

6.3 General remarks on market facilitation of the aggregator

The relative newness of the aggregator concept has an impact on the support of the aggregator concept by the market design. Explicit market rules for aggregators are not yet made in large numbers. The aggregator is not (yet) defined as a role in the market design and is currently more treated as a (new) function. Therefore, market parties are testing the market design by exploring these new aggregator activities to identify the relevant market rules. The above description of market support of the different aggregator types provides an initial analysis of the market facilitation for the aggregator typology. However, there are also some general observations that apply to the generic facilitation of aggregators.

Firstly, the Dutch electricity market design makes a distinction between small and large consumers, as also described in section 6.1.1. This has a big influence on the support for the aggregator concept. Interviewees emphasised this and argued that an aggregator that interacts with large consumers is better supported than aggregators that engage with small consumers. There is more market freedom for parties to create aggregator propositions for large consumers because the regulatory framework is less complicated. Consumer protection rules and licensing is to a lesser extent needed when market parties interact with large consumers. This applies to a greater or lesser extent for all types that are described in the aggregator typology.

Secondly, the liberalization process of the electricity markets resulted in many market rules, but also in freedom for market parties to operate. Several participants in this research emphasized this market freedom as important in the support of the aggregator concept. Rules, regulations and structures have been constructed with a market-based approach. This allows the monetization of flexibility within the electricity market. However, ambiguity is present in which market rules apply for aggregators or that new rules should be constructed. Various interviewees argued that clarity of the applicability of present rules and regulation on the aggregator concept can already result in a large degree of transparency. This transparency can then result in the support of the development of the aggregator types as it is better defined what and how they are allowed to operate.

Chapter 7

Aggregator value propositions and value capture

In this chapter, an elaboration will follow about the business models of aggregators. Firstly, the typology of chapter 5 will be used to analyse the value propositions of the different aggregator types and to explain the value creation by aggregators. Secondly, value capturing in the form of financial benefits will be discussed in more detail. This all will assist in answering the fourth sub-question: *How are aggregators creating and capturing value?*

7.1 Value proposition and aggregator typology

The following sections describe the main characteristics of the value proposition of the different models of the aggregator typology. Empirical cases are being used to exemplify the value propositions and value creation of the different aggregator types. The values identified by Niesten and Alkemade (2015) are used to explain the values of the different stakeholders. The created value for the prosumer and for the aggregator are being described for each aggregator type.

7.1.1. Combined Aggregator-Supplier

The value proposition of the combined aggregator-supplier type is characterised by the aggregator providing a service to the prosumer that includes both the supply of electricity and using flexibility at the prosumer side. The value proposition is an integrated proposition where both the supply of electricity and the monetization of flexibility are combined.

Active combined aggregator-suppliers in the Netherlands

Multiple market parties are active in the Netherlands that have a business model in the form of a combined aggregator-supplier structure. Two different examples are being described below, the first addressing large-consumers, while the other focus on small consumers.

Powerhouse

Powerhouse is one of the companies that can be categorized as a combined aggregator-supplier. Powerhouse proclaims not to be a conventional energy supplier, as they distinguish themselves by providing an online trading platform that enables greenhouses, factories, cold stores and other electricity users to trade electricity by themselves (Powerhouse, n.d.).

Powerhouse is providing market access to different electricity markets. This is done with a product that is called the Powerhouse Energy Platform. The proposition of Powerhouse includes next to sourcing electricity also the possibility to create value from flexibility. Value can be created with flexibility by smart bids, demand response based on imbalance prices or participate in ancillary services (Powerhouse, n.d.). Powerhouse supports its customers by providing marker access, know-how and possibly with hardware to control the energy consumption of assets.

This example demonstrates that market parties are active in the Netherlands that provide propositions to prosumers that enhance control over their energy bill. The platform of Powerhouse enables prosumers to use their flexibility in the sourcing process of electricity and thereby gaining control and benefit financially from it.

Eneco CrowdNett

Eneco CrowdNett is another example of a combined aggregator-supplier. The utility Eneco offers the CrowdNett product to its customers to increase the self-consumption of electricity and to provide flexibility.

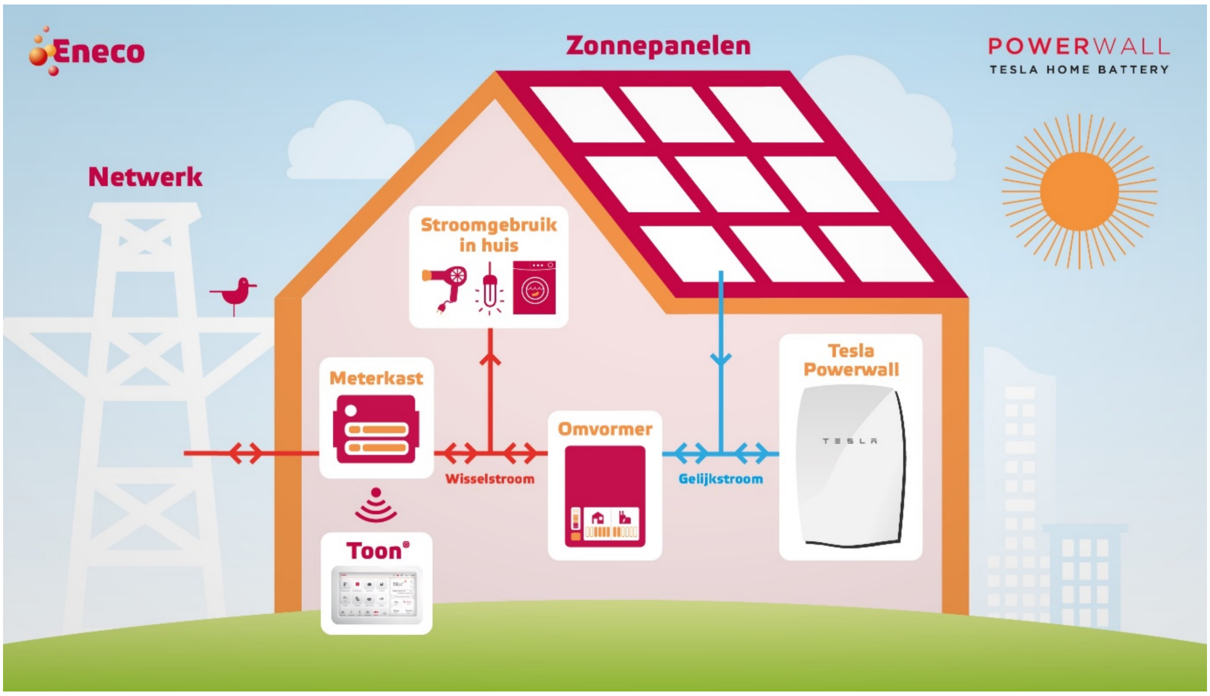

Figure 18 Illustration of CrowdNett product (Eneco, 2018)

CrowdNett is a product where a home battery is being sold to the prosumer. The prosumer can use this battery to increase the self-consumption and Eneco has an offer to use a part of the battery capacity for a financial compensation. Customers receive a remuneration of €400-500 a year if they let Eneco use 1/3 of the battery capacity for balancing purposes (Eneco, 2018).

The proposition of Eneco includes a conventional supply contract for electricity in combination with an extra service in the form of a home battery that provides flexibility. The CrowdNett example shows that different forms of value can be created by the aggregator. Value in the form of increasing self-consumption is created and prosumers receive financial benefits for renting out battery capacity. The CrowdNett product provides different forms of value for Eneco. The product offers an additional service to their customers and possibly increases customer loyalty. Value in the form of financial benefits result from using the battery for balancing purposes.

Value for prosumer

Different forms of added value for prosumers are present in value proposition of the combined aggregator-supplier. Three kinds of value are created for the prosumer, environmental benefits, financial benefits and comfort.

Firstly, value is created for the prosumer through environmental benefits. The integrated proposition of the combined aggregator-supplier may include flexibility options that also increase the self-consumption at the prosumer side. Increased self-consumption results in reduced CO_2 emissions, as shown in the research of Papagiannis et al. (2008). Secondly, the prosumer benefits financially from the proposition of the aggregator. Flexibility is monetized by the aggregator and the prosumer benefits from this in the form of a lower energy bill. Thirdly, the combined aggregator-supplier provides convenience for the prosumer as it acts as a 'one stop shop'. The combination of electricity supplier and aggregator unburdens the prosumer as both the supply of electricity and exploitation of flexibility is done by a single market party. Prosumers do not need to search for separate market parties for the supply of electricity and to aggregate flexibility. A recent study by the ACM (2018) confirms that the service level of suppliers is perceived by prosumers as an important element in the decision process of choosing a supplier. The combined aggregator-supplier uses its integrated proposition of supply and flexibility to increase the service level and to unburden the prosumer

Value for aggregator

The combined aggregator-supplier is commercialising the flexibility of the prosumer. This flexibility contains a financial value for the aggregator and can be monetized at different electricity markets.

The combined aggregator-supplier can exploit synergy benefits that result from operating both flexibility aggregation and supply activities. The synergy between these two activities can lead to lower sourcing costs of electricity by using the flexibility in the sourcing process. The aggregator then adjusts its electricity sourcing strategy by using the flexibility in the bidding process. Several studies observed the possible synergy benefits of combining the two activities (Gonzalez Vaya & Andersson, 2015; Parvania et al., 2013; Sarker et al., 2016; Vagropoulos et al., 2013).

7.1.2. Combined Aggregator-BRP

The value proposition of the combined aggregator-BRP is very similar to that of the combined aggregator-supplier. However, the combined aggregator-BRP is not fulfilling the role of supplier and only assists customers by unlocking, using and commercialising their flexibility.

Active combined Aggregator-BRP in the Netherlands

Business models related to the aggregator-BRP type are not (yet) being deployed in large numbers. One of the most prominent examples is a project that is coordinated by Scholt Energy Control.

ADO Den Haag Football Stadium.

The combined aggregator-BRP model is being used by Scholt Energy Control in a project that is located at the ADO Den Haag football stadium (Scholt Energy Control, 2018). In this project, two different market parties are active at the same connection. Therefore, the MLOEA regulation has been applied to clearly separate responsibilities and to allow Scholt Energy Control to operate as an aggregator on the connection of the stadium.

Figure 19 Battery at the ADO Den Haag Stadium (Scholt Energy Control, 2018)

Scholt Energy Control operates the flexibility of a battery of 750kWh and 20 EV charging stations (Scholt Energy Control, 2018). The battery and EV charging stations are being used for balancing purposes, smaller grid connection and possibly as a backup system for the stadium. Scholt Energy Control is next to aggregator also BRP for the second transfer point to which the battery and charging stations are connected.

This project demonstrates that a company can offer his specialized expertise and competencies to the prosumer while keeping operations of monetizing flexibility and electricity supply separate. The combined aggregator-BRP is exclusively dealing with the flexibility while another market party supplies electricity to the prosumer.

Value for prosumers
Value is created for prosumers by providing them the possibility to sell their flexibility with the assistance of another market party than the one that is supplying them electricity. This separation of electricity supplier and aggregator results in a greater freedom of choice for prosumers in organizing their flexibility. Prosumers have a large degree of freedom, control and opportunity to choose the right offer in the market.

Value for aggregator
The combined aggregator-BRP is creating and capturing value by generating revenue from flexibility that is sourced from prosumers. Combining the roles of aggregator and BRP makes it possible that the aggregator can operate without considerable interference of a supplier. Additionally, the aggregator is building specific competencies, as they offer products and services that are exclusively related to flexibility.

7.1.3 Aggregator as Service Provider

The aggregator as service provider has a rather different value proposition than the two previously discussed aggregator types. Most importantly, the aggregator as a service provider is not trading electricity or flexibility at its own risk. A service is created by the aggregator to unlock, control and to deal with the flexibility of prosumers. Therefore, only the ability and the means to use flexibility are being commercialized by this type of aggregator. Software and hardware platforms are often created to control flexibility. Access to these platforms is then sold as a service to different parties that are willing to use the flexibility.

Active Aggregator as service providers in the Netherlands
A relatively large ecosystem is present in the Netherlands where technological advancements in IT and energy are combined (Gangale et al., 2017). This results also in a multitude of companies that are actively exploiting an aggregator as service provider structure. Two examples will be briefly explained.

Lyv Smart Home
Lyv Smart Home is a software and hardware platform that controls smart home appliances and a home battery system (Lyv, 2017b). The home display 'Lyv Dash' is used to interact with the occupants and to provide them with relevant information.

The company Lyv does not act as an energy supplier and is only unlocking and aggregating flexibility for others (Lyv, 2017a). Lyv uses their software and hardware platform to control flexibility at the household level and offers access to this flexibility to other market parties. Lyv has been active in several smart grid projects as a technology provider where their platform has been used in practice.

R.E.X.

R.E.X. is a software product that enables market parties to control the consumption and production of assets to unlock flexibility (EXE, n.d.). R.E.X is developed by Energy eXchange Enablers, which is a subsidiary of the DSO Alliander. The R.E.X software platform is using real-time energy prices to create value from the flexibility by trading electricity.

Flexible assets are connected to the R.E.X. platform and electricity generation or consumption is controlled by the software. Preferences of the degree of flexibility are being entered in the software, like preferences for self-consumption or maximum degree of peak shaving. The software then trades electricity intelligently by using the flexibility in the sourcing or selling process. EXE (n.d.) argues that with the use of the R.E.X. platform 15-30 % of energy costs can be saved.

The two examples described above illustrate business models that use information technology (IT) cleverly within the electricity market. This is also one of the most distinctive elements of an aggregator as service provider compared to the other types. IT is being used to build capabilities and services that create value for both the prosumer and for the buyer of the service.

Value for prosumers

Value is created for prosumers in enhanced control over their flexibility. One of the most important features of the aggregator as service provider is their sophisticated hardware and software platform to control the flexibility. Prosumers can interact with this platform to see what is happening and to set their preferences. Therefore, the platform enables prosumers to take greater control over their flexibility.

Value for aggregators

The aggregator is creating value by providing a service and by not selling flexibility at its own risk. Financial benefits are being created by selling a service in the form of unlocking, access and control over flexibility. Therefore, the aggregator as service provider is not exposed to risks that come with the trade of flexibility. The intermediary function of the aggregator is connecting market parties that demand flexibility with prosumers that can provide flexibility.

7.1.4 Delegated/Broker Aggregator

The delegated/broker aggregator builds its value proposition around its core activity, aggregation of flexibility. The delegated/broker aggregator is not adopting any additional role as a supplier or BRP. This allows the delegated aggregator to specialize in aggregating flexibility.

Active delegated/broker aggregators in the Netherlands

Different delegated/broker aggregators are active in the Netherlands and operate in different fields. The delegated aggregator is for example emerging in the field of EV smart or additional applications of backup power systems. Two different example business models of a delegated/broker aggregator are being described below.

Jedlix

Jedlix is a company that is specialized in creating value by smart charging electric vehicles (EVs). A smartphone app and a connection with the charge station/EV are being used to unlock flexibility from the charging process (Jedlix, 2018). Drivers need to indicate their expected departure time so Jedlix can generate smart charging strategy within a timeframe. The intelligence of the Jedlix platform makes sure that the battery will be fully charged at the departure time. The charging process will be optimized within the timeframe taking several factors such as hourly electricity prices, imbalance prices, grid constraints etc. into account

The charging strategy of Jedlix is based on combining information about electricity wholesale electricity price with a real-time imbalance price forecast. The resulting flexibility of the smart charging will be commercialized in the ancillary service market or by voluntary balance contribution (Stegmann, 2017). A part of the profits that result from this will be rewarded to the EV owner. Co-founder of Jedlix, Taco van Berkel stated in an interview with the automobile magazine Autoweek (2017) that users of the Jedlix app can expect a reward of around ten euro a month.

NL Noodvermogenpool (Actility)

NL Noodvermogenpool is a company that aggregates capacity from clients that can adjust their electricity usage or production in an upward and downward direction (NLNVP, 2018). The aggregated capacity will be used to participate in the mFRR ('noodvermogen') ancillary service of TenneT. The pool consists currently of 60 MW in an upward direction by generating more or use less electricity (NLNVP, 2018). Mainly hospitals, water utility companies and data centres are providing this kind of flexibility by switching on their backup power systems temporarily. NL Noodvermogenpool has 120 MW available in a downward direction by temporarily generate less electricity or use more. This flexibility is mainly provided by biodigesters, CHP facilities and waste incineration plants.

NL Noodvermogenpool is in contact with TenneT and is responsible for the delivery of mFRR if TenneT requests for it. Automatic controllers are being used by NL Noodvermogenpool to control the assets that form the pool. Additionally, metering devices are operated by NL Noodvermogenpool to verify the supply of mFRR and for a fair distribution of revenues.

The above described examples illustrate two very different companies that are specialized in a certain activity. Specialization is an important element in the business model of a delegated/broker aggregator. These types of aggregators distinguish themselves by focussing on one specific activity and do this as best as possible, auxiliary activities, like BRP or electricity supply are being left to others.

Value for prosumers

Value is created for prosumers with the specialization of the aggregator. Increase in comfort and financial benefits and can arise when the aggregator gains expertise in specific sorts of assets. The aggregator can become an expert in controlling and optimizing specific sorts of assets. The established know-how assists the aggregator in creating value propositions that provide extra comfort to prosumers. For example, an aggregator with expertise in controlling EVs can create an application that unlocks flexibility from the charging process but also makes sure that the EV is always fully charged in the morning. Furthermore, the comprehensive expertise in specific sorts of assets or flexibility can provide the aggregator a competitive advantage compared to aggregators that do not have extensive expertise in these sorts of assets. The expertise of the aggregator can be used to improve the monetization of the flexibility and generate larger financial benefits for the prosumer.

Value for aggregators

The delegated/broker aggregator creates value by creating products that focus on a specific type of flexibility. This specialization could provide the aggregator a competitive advantage that can be used to leverage larger financial benefits. Specific know-how of assets assists the aggregator in optimizing his product to the prosumer and optimize the process of monetizing flexibility.

7.1.5 Prosumer as Aggregator

The value proposition of the prosumer as aggregator is characterised by prosumers taking control. The prosumer decides to act as an aggregator. Flexibility in assets of the prosumer is aggregated into a portfolio and will be traded by the prosumer at its own risk.

Active prosumer as aggregators in the Netherlands

For large-scale consumers it is not uncommon to take energy and flexibility control into own hands. Large-scale consumers that transition from the use of fossil energy to renewable energy are increasingly sourcing their own electricity and take more direct control (Ministerie van Economische Zaken, 2016b). One example of such a company is AkzoNobel Chemicals.

AkzoNobel Chemicals

AkzoNobel is a chemical company that operates multiple chemical production facilities in the Netherlands, in Delfzijl, Hengelo and Rotterdam (AkzoNobel, 2018). CHP electricity generators are located at several of these locations The total installed capacity of these generators is more than 500MWe (van de Putte, 2014). The average electricity demand for electricity is only 300MWe, which results in possible flexible operation of the CHP plants.

Furthermore, several hundred MWs of electrolysers are being used by AkzoNobel in different production processes (van de Putte, 2014). Flexibility from these assets is being unlocked by adjusting the chemical production at moments when electricity prices make this profitable.

Value for prosumer

Value is created for the prosumer by taking control over the trade of flexibility. Prosumers can decide, how and with who they like to trade the flexibility. This creates independence, but also creates a burden on the prosumer to operate its own flexibility.

The prosumer takes an active role in the electricity system by participating as an aggregator. This requires knowledge and capabilities to act in the electricity market. Market access and expertise is necessary to monetize the flexibility and to control the flexible assets according to the requirements of the market.

7.1.6. DSO as Aggregator

The DSO as aggregator model is heavily regulated, as DSOs are natural monopolies. One interviewee questioned if it is socially responsible if the DSO is allowed to aggregate flexibility on a small scale if this is not done by commercial aggregators. The DSO as Aggregators main driver would be to use the flexibility for congestion problems in the distribution grid. For example, the DSO needs very local and a minimum amount of flexibility in a specific neighbourhood. Commercial aggregators may be reserved in actively unlocking this kind of flexibility, because a lot of money and effort needs to be invested for only a small amount of flexibility. The DSO acting as an aggregator may then be a solution to unlock flexibility in a cost-effective way.

Previously, in chapter 6, it was discussed that the presence of a DSO as aggregator is currently impossible within the Dutch regulatory framework. Therefore, no examples are currently present of an aggregator that is actively operating a business model of this type.

7.2 Value capture by aggregators

A key component of the business model of aggregators is retaining a part of the created value, value capturing. One of the most important elements in value capturing by aggregators is creating revenue from the aggregated flexibility. Revenue is mostly created by trading flexibility. However, flexibility can be traded in several ways and with several different actors.

Dethlefs et al. (2015) argue that aggregators can sell flexibility to three different actors: the BRP, DSO and TSO. Firstly, the BRP can use flexibility to balance its portfolio. Flexibility is than used to solve imbalances that may be present in the portfolio of assets under control of the BRP. Secondly, the DSO can use flexibility to solve issues for congestion management. Thirdly, the TSO can use the flexibility to fulfil its obligation of balancing the grid. Balancing ancillary services could be a specific product where the TSO requests this flexibility. Additionally, the TSO can also use flexibility to solve congestion on the transmission grid.

The aggregator can trade flexibility also in three other ways, namely: at the day-ahead market, intraday market and possibly in capacity markets. These markets can be used by an aggregator to sell the aggregated flexibility.

Next to revenue, investments are essential to capture value. Investments in both physical and knowledge-based capital are necessary to create and eventually capture value. The example of the combined aggregator-supplier CrowdNett in section 7.1.1 shows investments in battery systems. Scaling up these systems by deploying it at more prosumers is highly capital intensive, as battery systems are costly. While other aggregators operate a strategy with investments in more intangible or knowledge-based assets like software. The delegated/broker aggregator Jedlix invests in knowledge-based capital to specialize in controlling and optimizing the EV charging process. Investments are made into an IT software platform to support their operation. These investments can be high, but results in capabilities that are less capital intensive and more easily to scale. Therefore, more capital intensive investments are necessary to use physical assets to unlock flexibility compared to more knowledge-based assets like software.

Interviewees in this research have been asked to provide their insights about the electricity markets in relation to the aggregator. Participants were asked to rank the different electricity markets according to the appropriateness for aggregators. Specifically, participants were asked to rank the markets from best (1) to worse (6) according to how relevant these markets are for aggregators to participate. This ranking assists in building insights of how aggregators monetize flexibility and how this results in value creation in the form of financial benefits. The results of this ranking are visualized the following boxplot.

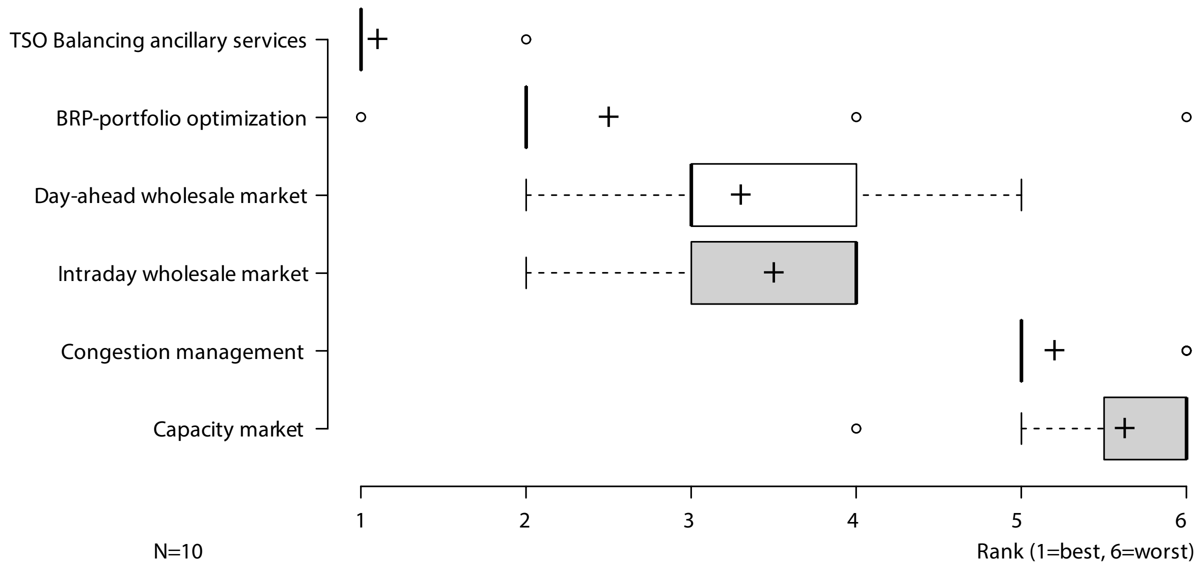

Figure 20 Boxplot diagram of ranking of markets according to appropriateness for aggregators. Ranked from 1 to 6, with 1 being the most appropriate market and 6 the worst.

7.2.1 TSO balancing ancillary services

All except one ranking participant argued that the TSO balancing ancillary service market is most suitable for aggregators. They indicated that the financial rewards can be large in this market and this has attracted the attention of many businesses. Additionally, market parties indicated that entry barriers for these markets have recently been lowered.

Financial gains

The FCR, aFRR and the mFRR products provide all substantial rewards for market parties that are contracted by TenneT to provide these kinds of reserve capacity. Compensation payments are made for the availability of capacity and/or for operational costs.

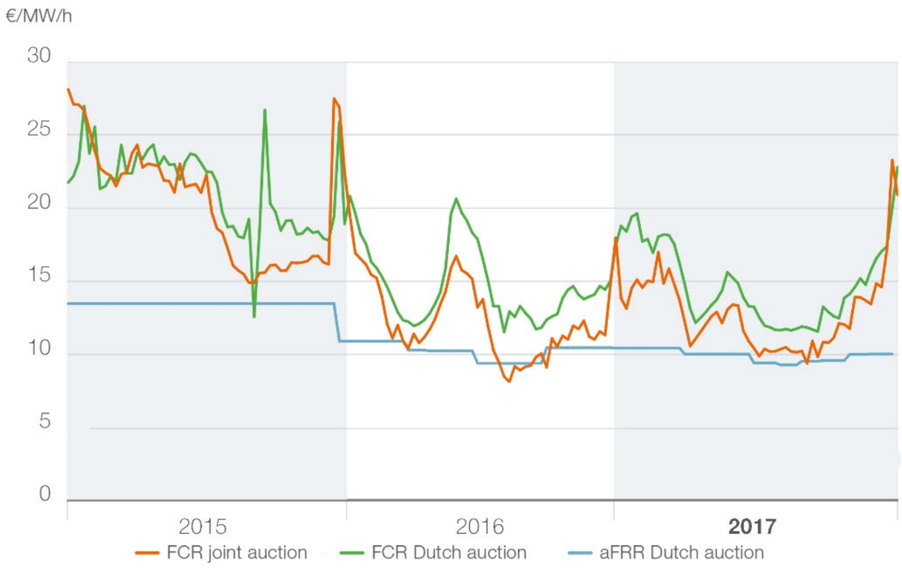

Figure 21 FCR and aFRR capacity price development (TenneT, 2018f)

The above figure shows the capacity prices for FCR and aFRR contracts in the Netherlands. Capacity payments in 2017 for FCR ranged between 10-23 €/MW/h and aFRR moved around 10 €/MW/h (TenneT, 2018f). Parties delivering aFRR receive next to the capacity payment also an energy price for the provided balancing energy.

Entry barriers

TenneT has recently changed the product specification of multiple ancillary services products. Since June 2018 it is easier for aggregators to participate in auctions for delivering FCR (TenneT, 2018c). The conditions and prequalification have been updated that allow aggregators to provide FCR with a pool of assets instead of a single asset. Furthermore, a pilot project started in September 2018 to investigate the possibility of aFRR provided by aggregators (TenneT, 2018a). Finally, the mFRR product changed in January 2017 into two different products, one for upward- and one for downward reserve power (TenneT, 2016). Earlier, it was required to deliver both up and downward emergency power. The modification of the mFRR product makes the market better accessible for aggregators that have a pool of assets that can only provide flexibility in a single direction.

7.2.2 BRP-portfolio optimization

Using flexibility to optimize the portfolio of a BRP has been ranked second by the majority of participants. Some suggested that flexibility can most easily be monetized by controlling assets with the voluntary balancing contribution, using the published near real-time imbalance price. Frunt (2011) compared the rewards of voluntary balancing contribution with participating in the ancillary services market and concluded that voluntary balancing contribution results in lower rewards while posing higher risks. The market profitability of trading flexibility with the voluntary balancing contribution mechanism is subjected to the volatility of balancing prices (Hylkema, 2016). Revenue from trading flexibility in this way is therefore very sensitive to changes in the balancing market and imposes risks on the aggregator.

7.2.3 Day-ahead market

The day-ahead market is on average ranked at third place, but results varied between ranks of second till sixth place. The day-ahead market is the most liquid Dutch wholesale market where the majority of electricity trading volume is taking place (EPEX SPOT SE, 2016). Three market parties mentioned the day-ahead market essential for trading flexibility. The liquidity in this market makes it easy to find a buyer or seller. The Dutch day-ahead market is operated by EPEX and a membership is required to participate in this market. EPEX is charging an entrance fee of 25.000€ for new entrants and an annual membership fee of 10.000€ per member (EPEX SPOT SE, 2018). Two interviewees argued that these fees may pose a barrier for aggregators to enter the market, as entering the day-ahead market requires substantial investments.

7.2.4 Intraday market

There is disagreement between participants of the rank of the intraday market. This is also visible in figure 20, the rank of intraday ranges between second and fourth place. Four interviewees described the intraday market as better accessible compared to the day-ahead market. The minimum bid size and transaction costs are lower at intraday platforms like ETPA (ETPA, 2018) However, liquidity in the intraday markets is still relatively low. The intraday markets are still developing in the Netherlands, with new initiatives like ETPA and the EPEX continuous market (EPEX SPOT SE, 2016; ETPA, 2018). Trading volumes in these markets are increasing but significantly lower than the day-ahead market. Low liquidity means low competition and could mean that a single trade of aggregator is impacting the market in such a way that his profitability decreases (Weber, 2010).

7.2.5 Congestion management

Congestion management is ranked on average at the fifth place. Interviewees argue that aggregators can unlock a promising volume of flexibility that could be provided to the DSO for congestion management. The decentral nature of flexibility that is pooled by the aggregator makes it particularly suitable for solving congestion on the distribution grid.

Thus far, markets for DSO congestion management are still in the pilot phase. The three large DSOs in the Netherlands, Alliander, Enexis and Stedin are all experimenting and exploring market-based approaches that should prevent congestion. Alliander is experimenting in the DYNAMO project, Enexis in the Interflex project and Stedin in the Coflex and Hoog Dalem projects (Goes & Volkerts, 2017).

TenneT operates a market-based mechanism to manage congestion on the transmission grid by redispatching electricity (Glismann, 2018). Redispatch is realized by requesting market parties to lower the electricity generation in the congested area and increase generation at another location that is outside the congested area. Market parties can provide their bid for adjusting their electricity generation or offtake. Bids have a minimum bid size of 1 MW and a minimum activation time of an hour (Glismann, 2018). Market parties can provide voluntarily bids, but units of more than 60MW are obligated to bid. The redispatch product is similar to the balance ancillary products and could be an interesting additional revenue stream for aggregators. Aggregators can participate in redispatch by making voluntarily bids.

TenneT, Stedin and ETPA have started a pilot project to address congestion with a market-based TSO-DSO congestion management instrument. The intraday congestion spread (IDCONS) pilot project uses optional location data that traders can add to their intraday orders at ETPA (Glismann, 2018). The DSO or TSO may use suitable orders at ETPA to prevent congestion. This platform is still in pilot phase but already presents additional value capture possibilities for aggregators.

7.2.6 Capacity market

The capacity market is ranked lowest by the participants of this ranking. The electricity market design in the Netherland is based on the energy-only principle which implicates that payments are only made for energy and not for capacity, with the expectation of the balancing products that do receive a price solely for the provide capacity (Cramton, 2017). Therefore, no capacity market is currently present in the Netherlands aside from some capacity priced balancing products.

7.3 Concluding remarks

The business models of aggregators are still maturing but, the described examples demonstrate that there are a variety of aggregators active in the Dutch electricity market. They differ in how they organize their value proposition and how they capture value. The used typology assists in structuring the different aggregators and the value creation and capture process.

One of the interviewees described that the trading strategy of aggregators is often not based on participating in only one single market, like for example the ancillary service. Aggregators can leverage the flexibility to create revenue in different markets. Combining value creation in different markets or value-stacking makes the trading strategy more profitable.

The majority of interviewees identified that participating in TSO balancing ancillary service market is currently most profitable. Prices for flexibility are high in these markets, but there are also technical constraints like response time etc. The product specifications have recently been changed and we have to wait and see if more market parties will participate and if competition will have an effect on market prices. The market for using flexibility for BRP-portfolio optimization is also attractive for market parties. Rewards for voluntary balancing contribution are lower compared to the TSO balancing service products, but still substantial when trading strategically. Trading in the intraday and day-ahead market is less attractive as volatility and prices are substantially lower. However, these markets may be imperative as for example in the case of a combined aggregator-supplier, as also electricity should be sourced. The congestion management market is still evolving and can be already an attractive additional value capture opportunity for aggregators.

Chapter 8

Outlook: Trends and the influence on the position of aggregators

In the course of this research, several trends have been identified that could impact the future situation for aggregators in the Netherlands. Various important trends will be discussed together with the possible future impact on aggregators. This assists in answering the fifth sub-question: *How will industry and technology trends shape the position of the aggregator in the future?*

8.1 Industry trends

8.1.1 The upcoming new EU electricity directive

On 30 November 2016, the European Commission presented a proposal for a new legislative package for regulating the European energy market (European Parliament and the Council, 2017). This package is explicitly aimed at making the electricity market more flexible, encourages decarbonization and stimulates innovation. It is recognized that Europe's electricity system is changing profoundly and rapidly due to the increasing share of electricity produced by renewables (European Commission, 2016). The proposed electricity directive sets a framework for the market participation of aggregators (European Parliament and the Council, 2017). Member states have to ensure that aggregators can participate in the electricity market and need to set transparent rules and responsibilities for market parties.

The proposed electricity directive is still in the trilogue negotiation phase between the European Commission, Parliament and Council (Erbach, 2018). However, all parties have presented their stance and its expected that the trilogue phase will end soon. This directive, when it becomes into force, will influence the position of aggregators profoundly. The framework and increased transparency of roles and responsibilities will provide direction for aggregators to position themselves in the electricity market. The directive requires all member states to create transparent and fair rules to allow aggregators to participate in electricity markets. The aggregator should be able to participate in a non-discriminatory manner in all electricity markets without the consent of the final customer's electricity supplier. Additionally, the proposed directive imposes that transparent rules and procedures regarding data exchange should be in place. And importantly for aggregators that operate independently of the suppliers BRP, procedures should be created to coordinate compensation between aggregators and other market parties for possible imbalances that may result from the activation of flexibility by the aggregator.

8.1.2 Disruption in the electricity industry

The traditional business model of utilities is being challenged (Bryant et al., 2018). The traditional utility is focussing on generating profits through the sale of energy to end-customers by generating electricity with large-scale power plants that often use non-renewable fuels. The increasing share of VRE generation capacity is placing the financial viability of the traditional utility under pressure (Ruggiero & Lehkonen, 2017). Therefore, utilities are looking to innovate by searching for new opportunities to create revenue that are beyond a commodity-driven approach focused on electricity sales.

The impact of electricity generation from VRE sources on the business model of utilities is currently still relatively low as only 9 % of the electricity demand in the Netherlands is generated from VRE sources (ECN, 2017b). However, the further integration of VRE sources in the electricity system will increase substantially in the upcoming years. This will increase the pressure on the business model of utilities drastically.

New entrants with new business models are increasingly entering the market (Boscán & Poudineh, 2016). Decentralized assets and advancements in ICT are being used by new entrants to create new products and services. Boscán and Poudineh (2016) argue that these new products and services are appearing more frequently in the market, but are creating a chaotic picture. Still, it is argued that these entrants share some common features. These new entrants have considerable lower fixed costs compared to incumbents that rely on traditional large-scale assets (Boscán & Poudineh, 2016). New entrants depend more on nontraditional knowledge-based assets instead of physical assets. This together is challenging the conventional business model of utilities that enjoys a relative undisputed position with consumers act as the passive end of the value chain.

8.2 Technology trends

8.2.1 Digitalization

The electricity industry is adopting digital technologies at a rapid pace (Post & Aazami, 2017). Information communication technologies (ICT) and especially emerging technologies such as cloud computing, Internet of Things, big data analytics and smart grids are reshaping the landscape of the electricity industry (Zhou et al., 2016). The research of Shomali and Pinkse (2016) shows that many new business opportunities arise with smart grid technology. Incumbents and new entrants are adopting new business models that are enabled by new digital technologies. These new business models are changing the composition of the value chain by an increasing number of new players. Furthermore, the value proposition in new business models is pivoting from selling electricity to selling energy related services (Shomali & Pinkse, 2016).

8.2.2 Storage

Schmidt et al. (2017) argue that the development and deployment of electrical energy storage (EES) could play a critical role in enabling the integration of intermittent renewable sources. EES could assist in balancing inflexible or intermittent supply with demand. The research of Schmidt et al. (2017) shows that the cost of EES systems has decreased rapidly in the past several years. Furthermore, it is expected that the cost of EES systems will decrease even further with increasing cumulative investments and related cost reductions in the future.

Storage technologies are one of the drivers that leads towards a new system in which consumers produce, use, store and sell electricity (Parag & Sovacool, 2016). This so called ‘prosumer era’ by Parag and Sovacool (2016) triggers innovation in business models. Ilieva and Rajasekharan (2018) show different business models with EES technology that disrupt the energy sector. They argue that storage technology could act as a platform where value is created for all members connected to the platform. The example that they provide is the “storage as service platform” that offers both services to households (e.g. home battery systems) and to large-scale storage clients like industrial/commercial entities. Storage technology is a driver for the development of opportunities for the aggregator. Technological advancements in storage lead to new innovative business models that could open new business for aggregators.

8.3 Trends in relation to the aggregator typology

The above described trends influence the development of the aggregator in the future. The effects of the trends on the aggregator will be described by using the constructed aggregator typology of chapter 5. Mainly the influence on the combined aggregator-supplier, aggregator as service provider, delegated aggregator and prosumer as aggregator type will be discussed.

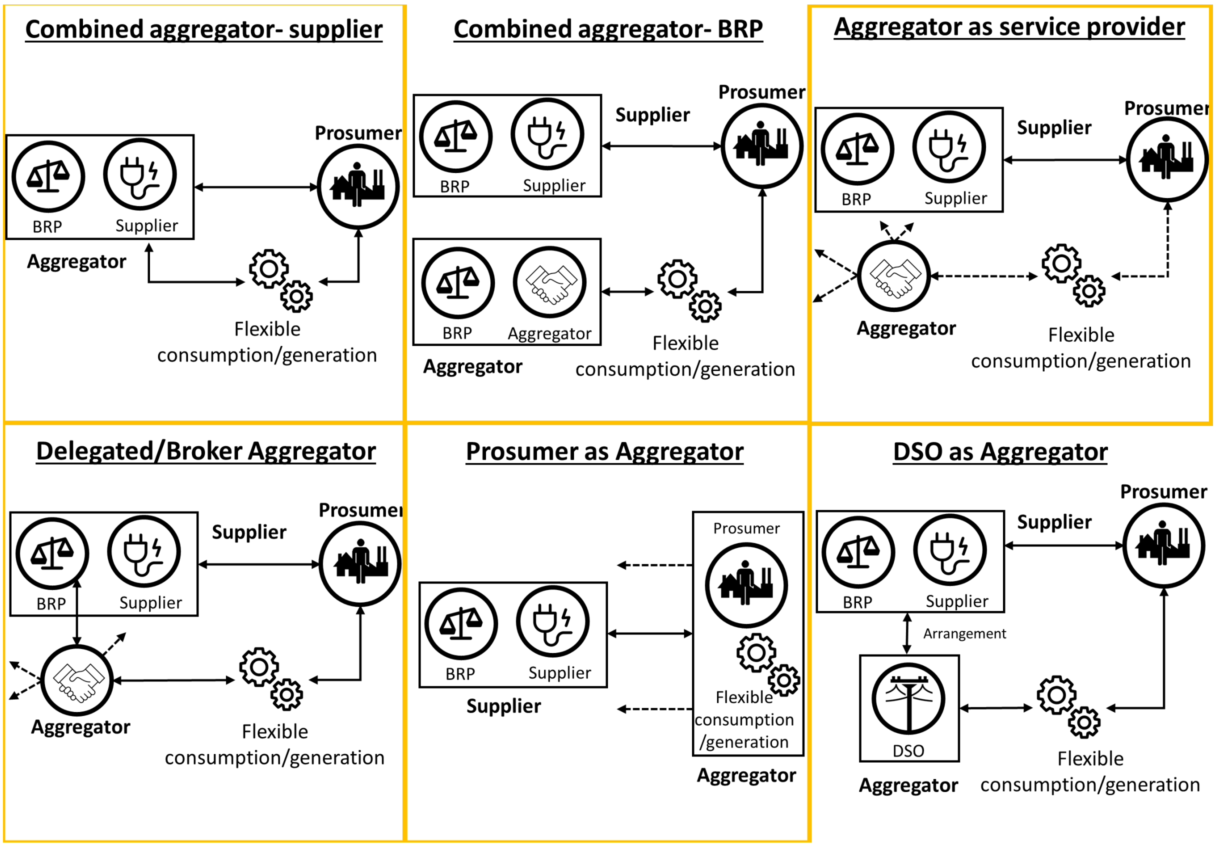

Figure 22 Overview of aggregator typology and the influence of trends

Disruption in the electricity sector stimulates incumbents to innovate. The combined aggregator-supplier model is an example of such innovation where incumbent utilities search for new revenue streams by adopting flexibility aggregating activities next to the conventional electricity sales activity. This type of aggregator model is closely related to the existing activities of electricity suppliers, as the traditional supply contract is expanded with flexibility options. Therefore, utilities that are willing to expand their activities with aggregator activities are most likely to adopt the combined aggregator-supplier model. Increasing disruption in the electricity sector and the urgency to innovate could result in increasingly more utilities adopting some form of the combined aggregator-supplier model in the future.

Advancements in ICT and the shift in the electricity sector from a commodity-driven approach to a service-driven approach may foster the number of businesses adopting the aggregator as service provider or the delegated/broker aggregator model. New entrants adopting digital technologies may lead to specialized companies that develop capabilities and competencies in a specific field. This can be used in business models in the form of the aggregator as service provider or delegated/broker aggregator model.

The new EU electricity directive will influence all types of aggregators, but the aggregator as service provider, delegated/broker aggregator and prosumer as aggregator types, may be particularly affected. The directive provides especially direction to these type of aggregators, because member states need to create transparent and fair rules to allow aggregators with new business models to participate in electricity markets. Furthermore, the proposed directive states that member states should ensure that there are no undue contractual restrictions in place (European Parliament and the Council, 2017).

The trend of increasing participation of end-users as prosumers in the 'prosumer era' as Parag and Sovacool (2016) call it, has an influence on the adoption of the prosumer as aggregator model. Even though it is uncertain how widespread and to what extent the 'prosumer era' will develop in the future, the increasing number of end-users involved with distributed generation and storage will foster adoption of the prosumer as aggregator model. Furthermore, active energy consumers or prosumer participation in the electricity markets is encouraged in the new EU electricity directive and the responsibilities and roles are being formulated.

8.4 Market parties outlook and aggregator typology

Interviewees were requested to express their views on the market facilitation of aggregators in the future. The same ranking question about market facilitation of the aggregator types, as previously described in chapter 6, of was asked for the situation in 2030. The results of this question and the earlier discussed results of the question for 2018 are visualized in figure 23.

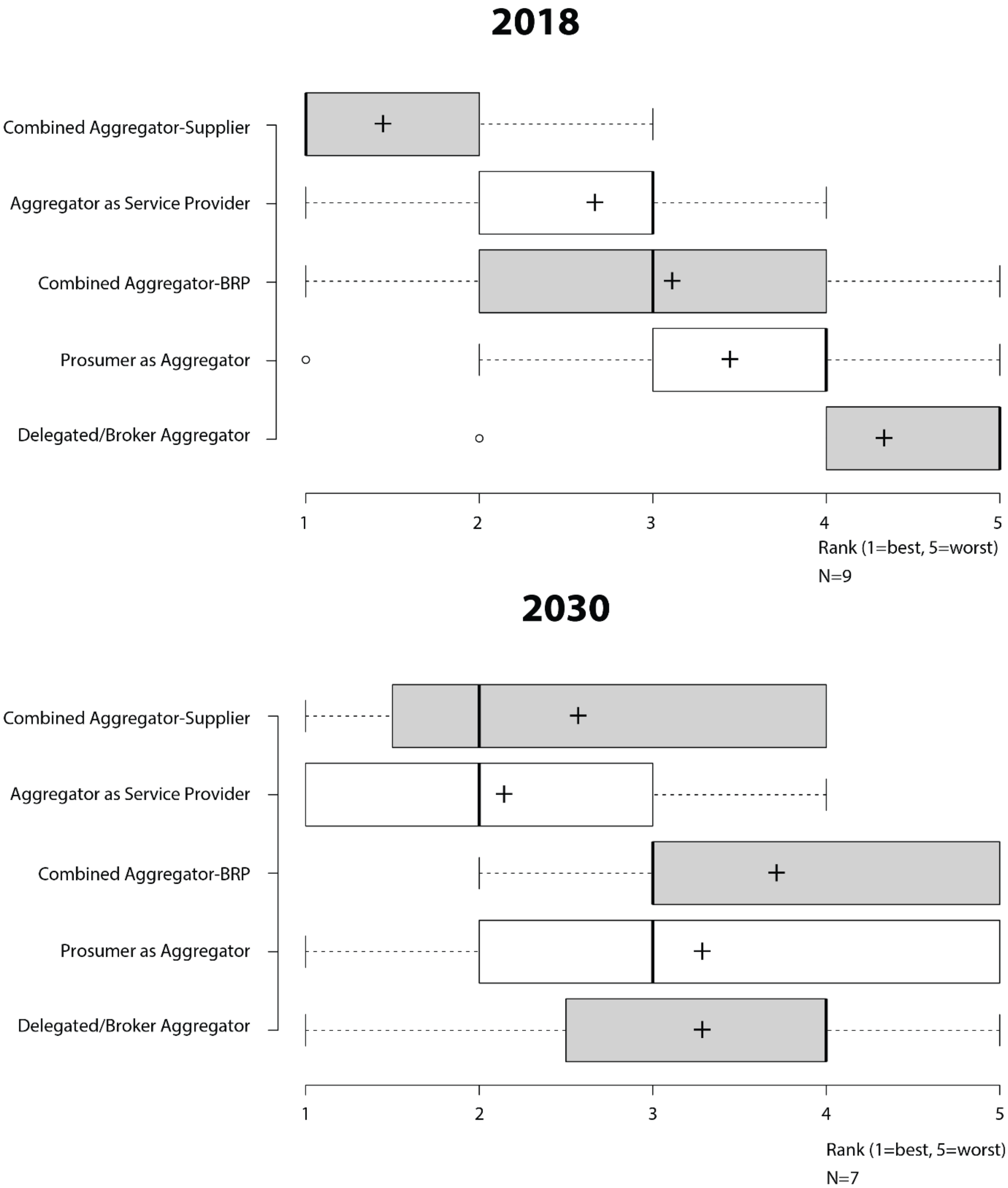

Figure 23 Boxplot diagram of the market facilitation ranking of the different aggregator types in 2018 and 2030. Ranked from 1 to 5, with 1 being the best facilitated and 5 the worst.

Comparing the ranking of 2030 with 2018 provides insights about possible rearrangements in the market facilitation of the different aggregator types. Several interesting outcomes can be retrieved from the rankings.

Firstly, market parties had diverging opinions regarding the future facilitation of aggregators. This is reflected in the results of the ranking of 2030 as a large variation in ranking. Interviewees argued that they found it difficult to make statements about the aggregator in the future. It was commented that the aggregator concept is relatively new and still developing at a rapid pace. The progress in maturity of the aggregator concept made it difficult to make an outlook into the future.

Secondly, market parties ranked on average the combined aggregator-supplier and combined aggregator-BRP models lower in 2030 compared to 2018. Conversely, the aggregator as service provider and delegated/broker aggregator models ranked higher in 2030 compared to 2018. The same explanation for this shift was given by five interviewees. They argued that companies will perhaps shift their activities between now and 2030. It is argued that firms may shift from a model where electricity supply and flexibility are combined, the combined aggregator-supply model, to a model where firms focus on solely flexibility, like the aggregator as service provider or delegated/broker aggregator model. One interviewee commented that businesses are maybe adopting a combined aggregator-supplier model currently out of necessity, as the rules and regulations for this model are more fully matured. Another interviewee provided the argument that he envisioned a future where it is much easier to aggregate flexibility without adopting for the BRP role.

Thirdly, interviewees provided different views on the prosumer as aggregator model. The prosumer as aggregator model was described as desirable but not realistic by one interview. Arguments were given that with increasing integration of decentral energy systems in the future, prosumers should have the possibility to take control over their flexibility. Realistically, it would not happen very much as prosumers find it burdensome or difficult to act as an aggregator. Another interviewee identified this model as unnecessary as it was argued that it should be possible for prosumers to act as the aggregator in any of the aggregator models.

8.5 Concluding remark

Market parties assessed that in 2030 the aggregator as service provider and delegated/broker aggregator models will be better supported than in 2018. The combined aggregator-supplier and combined aggregator-BRP models decline in the ranking of 2030 compared to 2018. Industry and technological trends support this shift. The new EU electricity directive, disruption in the electricity sector, advancements in technology and changes in business models are all shaping the development of the aggregator.

Chapter 9

Conclusion

The aim of this thesis is to gain a thorough understanding of the aggregator concept in the context of the Dutch electricity market. This thesis tries to answer the following research question: *How is the aggregator positioned in the current Dutch electricity system and how could this develop in the future?* Five sub-questions have been constructed that are used to answer the main research question. This chapter will summarize the findings discussed in the earlier chapters and relate these findings to the main research question of this thesis.

9.1 Flexibility in the Dutch electricity system

This thesis started with an analysis of flexibility in the Dutch electricity system. The existing state of affairs regarding supply and demand of flexibility has been analysed, followed by a description of developments that could shape flexibility in the future. This analysis assists in answering the first sub-question of this thesis: *How is flexibility organized in the Dutch electricity system and what developments are expected in the future?*

Flexibility in the electricity system is necessary to cope with changes that occur in electricity generation and demand. Issues of flexibility are becoming more apparent with the integration of more variable renewable energy (VRE) in the electricity system. VRE sources like wind and solar are not as controllable as the traditional generation of electricity with fossil fuelled generators. This results in increasing demand for flexibility and the need of new sources that can provide flexibility.

The current low amount of electricity generated from VRE sources (9% in 2016) limits the need for flexibility to cope with VRE (ECN, 2017b). Flexibility is currently mainly needed to manage variability and uncertainty in electricity consumption and to less extent due to variability and uncertainty in VRE generation. Flexibility is currently primarily supplied by conventional power plants. The majority of electricity generation capacity in the Netherlands is fossil fuelled with coal (15 %) and natural gas (67 %) (TenneT, 2018f). Cross-border transmission capacity with neighbouring countries is currently another important source of flexibility.

The need for flexibility is expected to change rapidly in the upcoming years with increasing integration of VRE (especially offshore-wind). An extensive study of ECN (2017a) concluded that the amount of flexibility demand is expected to increase 30-40 % in 2023 compared to 2013. The largest growth in flexibility demand is expected to happen between 2030 and 2050 when an increase of 300% is expected compared to 2030. This increase in flexibility demand originates not only from increasing supply side variability and uncertainty, but also from increasing electricity demand due to electrification, displacement of conventional generation capacity by VRE and congestion on the electricity network. Developments in new technologies like demand response and storage are becoming more important when shifting from flexibility supplied by fossil fuelled generators toward low carbon flexibility. New forms of flexibility are being developed, which could come from new technologies but also from new actors. The aggregator is such a new actor or solution to unlock (new) flexibility.

9.2 Defining the aggregator in the Dutch electricity system

The main topic of this thesis is the aggregator. The aim of the second sub-question of this thesis is to clarify the aggregator concept and to describe how the aggregator is defined in the Dutch electricity system This analysis will result in answering the second sub-question is: *How is the aggregator defined in the Dutch electricity system?*

The aggregator as a new actor and as a formal role are interchangeably being used in literature. However, defining the aggregator as actor or as role has different implications. The aggregator as new market intermediary represents an actor that is active in the electricity market. Roles are defined in legislation and describe the responsibilities and intended behaviour of actors. The aggregator as an actor can adopt multiple roles like for example supplier and BRP, while the role of aggregator describes the tasks and function of aggregators explicitly in legislation. The activity of aggregation and the entity of a new intermediary are both used in describing the aggregator concept. Aggregation is a function of combining multiple customer loads or generation into a pool. The aggregator is a possible legal entity that could adopt this function in order to offer flexibility to other electricity system participants.

A typology of aggregators has been created with the use of literature review. This typology contains a classification of six different aggregator types. Three types represent an aggregator with a combined role, the combined aggregator-supplier, the combined aggregator-BRP and the DSO as aggregator. The three other types are non-combined aggregators that solely focus on flexibility. A visual overview of the aggregator typology and a table with explanation is provided on the next page.

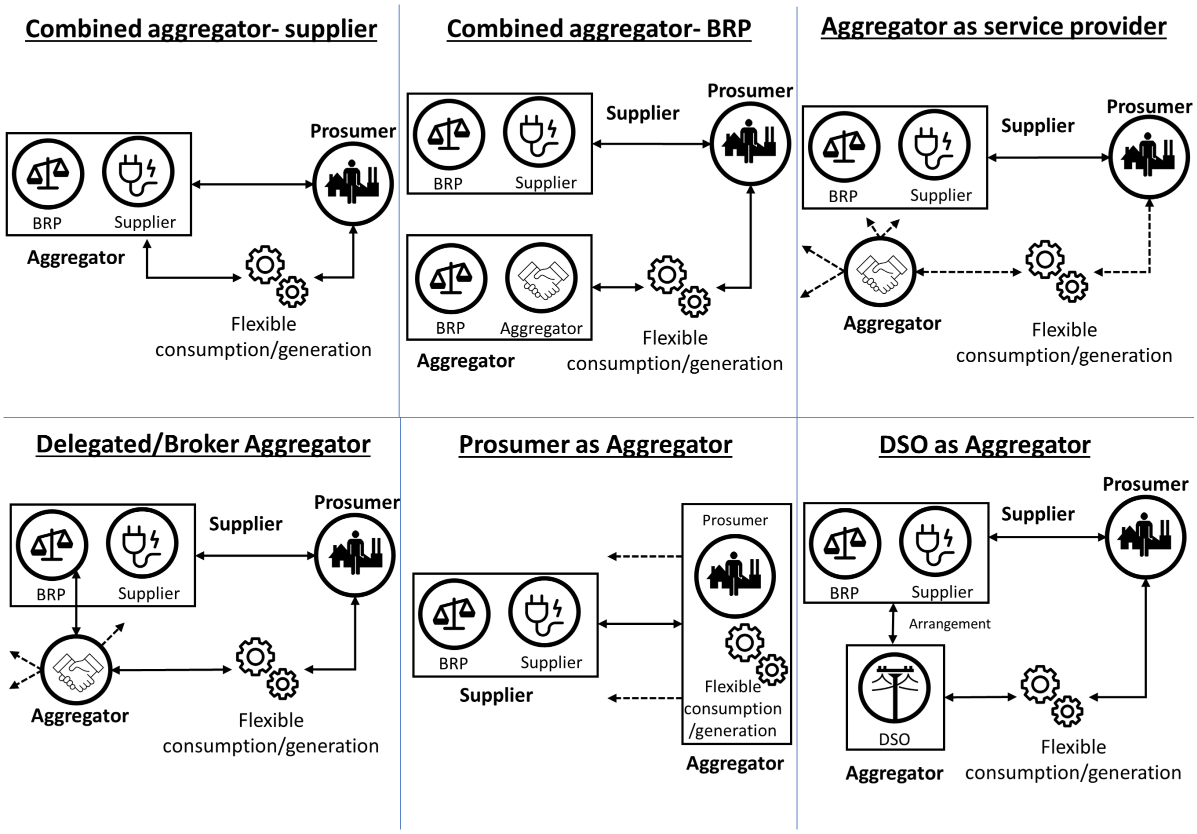

Figure 24 Overview of aggregator typology

Type	Explanation
Combined aggregator-supplier	Integrated model where the aggregator **both** aggregates the **flexibility** and **supply of electricity**. The aggregator provides the consumer a **supply contract including flexibility options**. There is only one BRP per connection point.
Combined aggregator-BRP	The aggregator **combines** his role of **aggregator** with that of **BRP**. There are **2 BRPs** on the same connection. Aggregator needs to **compensate** the supplier for the sourced electricity.
Aggregator as service provider	The aggregator acts purely as a flexibility provider for one of the other roles. The aggregator provides **the means to access flexibility** and offers this **access as a service** to other parties, instead of selling it on its own. The aggregator **does not trade flexibility** but **exclusively collects flexibility** from prosumers.
Delegated/Broker Aggregator	The aggregator **buys flexibility** form prosumers and **sells it at its** own risk to buyers. The BRP and aggregator make **arrangements** for the use of flexibility. The BRP of **the supplier is the only BRP**. The arrangement could include a compensation from the aggregator to the BRP for the activation of the flexibility.
Prosumer as Aggregator	**Large-scale prosumers** could choose to adopt the role of aggregator. They could **aggregate a portfolio** of flexible assets on their own.
DSO as Aggregator	The DSO aggregates flexibility for the purpose of **congestion management**. The roles of **BRP or supplier are not adopted** by the aggregator and is **only involved with the aggregation** of flexibility from prosumers.

9.3 Market facilitation of the aggregator

The market facilitation of the aggregator is studied in this thesis. The aggregator concept in the context of the Dutch electricity market has been analysed to answer the third sub-question of this thesis is: *How is the current Dutch electricity market facilitating aggregators?*

The aggregator is a relatively new concept. This newness has an impact on the support of the aggregator by the current electricity market design. Not many explicit market rules for aggregators have yet been made. The aggregator is not yet defined as a formal role in the market and it is currently more treated as a new actor and a new function. Assorted rules and regulations have been analysed in relation to the aggregator typology.

The analysis shows that especially the combined aggregator-supplier model and the aggregator as service model are well supported in the Dutch electricity market. The proposition of the combined aggregator-supplier is very similar to the activities that suppliers are currently undertaking. The combined aggregator-supplier integrates flexibility in the electricity supply contract and a single party interacts with the prosumer. The aggregator as service provider model benefits from not actively trading electricity but offering a service. Regulatory pressure is lower for this type of aggregator, because electricity market regulation is mainly concerned with the trade of electricity. The aggregator as service provider circumvents many of this regulation by operating a service-based business model instead of a community-driven business model.

The combined aggregator-BRP and prosumer as aggregator models have elements that make them well supported by the market, but other elements make these models difficult to function in the Dutch electricity market. The MLOEA regulation is an example of an element that supports aggregators to operate a combined aggregator-BRP model. However, interviewed market parties emphasized that this model results in severe complexity, as there are multiple BRPs active at the same connection. The prosumer as aggregator model is particularly appropriate for large-consumers. The lack of expertise and know-how of the electricity markets by small-consumers makes it more difficult for them to act as an aggregator.

The delegated/broker aggregator and DSO as aggregator are not well facilitated in the Dutch market. Complexity in contractual agreements makes the delegated/broker aggregator model difficult to operate. Comprehensive arrangements need to be made with (multiple) BRPs and prosumers about imbalances and redistribution of benefits and costs. The lack of explicit rules and regulations that facilitate these arrangements make this type of aggregator difficult to function. The activities of DSOs are heavily regulated and make it currently impossible for a DSO to act as an aggregator. The current regulatory framework concerning the DSO provides a clearly defined description of the tasks and obligations of the DSO and according to the national regulator, this task description does not include any activities related to the DSO as aggregator.

9.4 Value creation and capture of aggregators

In this thesis several business models of aggregators have been analysed. The value propositions of different aggregator types have been used to study the value creation and capture. This assisted in answering the fourth sub-question: *How are aggregators creating and capturing value?*

From the empirical cases it can be concluded that different kinds of values are created for the prosumer and aggregator. Three kinds of value are created for the prosumer: environmental benefits, comfort and financial benefits. Environmental benefits can be gained when the flexibility in the proposition of the aggregator increases the self-consumption of the prosumer. Benefits in comfort vary in the different aggregator models. The combined aggregator-supplier provides comfort as a single party interacts with the prosumer for both flexibility and electricity supply. The aggregator as service creates comfort by offering prosumers enhanced control over their flexibility. Financial benefits differ among the aggregator models. Prosumers get rewarded for offering their flexibility, but the level of reward varies among the type of flexibility and precise business model of the aggregator.

The empirical cases show value creation for aggregators. Value for the aggregators is mostly related to financial benefits, what reasonably can be expected as aggregators are often commercially orientated. Financial benefits for aggregators can be created by selling flexibility directly, selling a service or lower the sourcing costs of electricity. Additionally, companies that specialise in a specific field (e.g. EVs or emergency power) could create a competitive advantage with their extensive knowledge in that field.

Aggregators can capture value in several different ways. Flexibility can be monetized in six different markets. First, the TSO balancing ancillary service market. Entry barriers for this market have recently been lowered and interview participants described this market as lucrative for aggregators. Secondly, flexibility can be monetized by optimizing the portfolio of a BRP. This market is not as attractive as the TSO balancing market but still very attractive. Thirdly, trading in the day-ahead market is important for aggregators as the majority of electricity is traded in this market. Fourthly, the liquidity in the intraday market is still low, but the low minimum bid size and transaction costs make this market convenient for aggregators. Fifthly, suppling flexibility to the DSO or TSO for congestion management can be a lucrative additional revenue stream for aggregators. Lastly, a capacity market is currently not present in the Netherlands aside from some capacity priced balancing products.

9.5 Future role of aggregator

The last part of this thesis describes trends in the electricity industry and in technology that influence the aggregator. The impact of these trends on the aggregator is analysed to answer the fifth sub-question of this study: *How will industry and technology trends influence the position of the aggregator in the future?*

Disruption in the electricity market stimulates utilities to innovate and to expand their current business models. The combined aggregator-supplier type is an appropriate model for utilities to expand their proposition by including flexibility options. The aggregator as a service provider and the delegated/broker aggregator models are stimulated by advancements in ICT. Companies that focus solely on flexibility can use ICT to create business models that are less commodity-driven and more service orientated. The majority of interviewees emphasised that they foresee in the future more businesses that specialize solely in creating value from flexibility. The proposed new EU electricity directive is in line with this reasoning. It is proposed that member states adapt or create rules that lower entry barriers and provides a more transparent regulatory framework for aggregators. This should stimulate the participation of aggregators in the electricity market. The proposed directive requires member states to define clear and reasonable rules for the participation of aggregators.

There is a trend of more prosumer participation in the electricity system. The prosumer as aggregator type is a model that exemplifies this prosumer participation. The EU clean energy legislative package encourages active participation of prosumers. Creating and capturing value from flexibility is a process that requires substantial knowledge of the electricity market. Therefore, it is uncertain how the prosumer as aggregator model will develop in the future.

9.6 Main research question

With this thesis it was aimed to provide insights into the position of the aggregator in the current Dutch electricity system and to provide a better understanding of the possible future role of aggregators. This resulted in the following research question: *How is the aggregator positioned in the current Dutch electricity system and how could this develop in the future?*

The aggregator is an emerging concept in the Netherland. The search of additional and new sources of flexibility has fostered the development of the aggregator concept and the aggregator is progressively starting to establish in the Netherlands. This study showed that the position of aggregator can be described in three different ways: as a new actor, a formal role and a function. The constructed typology describes six different arrangements of positioning the aggregator as an actor, how the roles are formalized and what functions are adopted by the aggregator.

New entrants are joining the electricity market by using new technologies and by adopting new business models. The aggregator concept is used to describe these new actors in the electricity system. The described empirical cases show that several actors are currently active in the Netherlands that present themselves as aggregator. The aggregator actor represents a market party that is active in the electricity system and can adopt multiple roles, like the supplier or BRP role. Roles are formally defined description of tasks and responsibilities of an actor. Currently, there is no formal aggregator role defined in the Dutch electricity market model. The aggregator must take up other roles to participate in the electricity market. The aggregator can fulfil different tasks or functions as depicted in the typology. Principally, the aggregator is an actor that acts an intermediary between prosumers and other actors in the electricity system who wish to use the flexibility that is provided by the prosumers. Aggregation is described as the function that is being realized by the aggregator, by combining multiple sources of flexibility into a pool and offer this as package to other actors in the electricity system.

The constructed typology illustrates six different aggregator arrangements that describes the current position of aggregators. Developments that influence the future position of aggregators are also studied in this thesis. Industry and technology trends are fostering developments in the direction of the non-combined aggregators. Non-combined aggregators like the aggregator as service provider, the dependent/broker aggregator, the prosumer as aggregator are benefiting from using ICT and their service-driven approach to specialize in specific forms of flexibility. This specialization assists companies to focus on the core activity of innovating and developing new ways to unlocking and commercializing flexibility. These aggregators can specialize in activities that are related to specific forms of flexibility (e.g. from EVs or home batteries). New developments relating to aggregators need to mature further, be stimulated and realized to fully benefit from its potential.

Chapter 10

Discussion

The last part of this thesis provides a reflection on the outcomes of this study. The implications and limitations of the outcomes of the study will be discussed. Implications for market parties as well as for policymakers will be discussed.

10.1 Reflection on outcomes

Reflecting on the outcomes of this study, several topics should be discussed. Considerable political discussion is taking place about the independent aggregator and the results of this thesis should be interpreted within the right context. Some remarks are made about the non-exhaustive list of aggregator cases that are used in this thesis. Lastly, the relationship between the future role of the aggregator and political choices is described.

The constructed typology contains three types of aggregators that are classified as non-combined aggregators. These aggregators operate more isolated from the BRP and supplier compared to the combined aggregator-supplier or combined aggregator-BRP. The non-combined aggregators do not adopt a BRP or supplier roles and focus on aggregating flexibility. Currently, much discussion is taking place at national and EU level about the added value of having independent aggregators in the electricity markets. This concept of independent aggregator is similar to the aggregator concept still ambiguous and not fully matured. The concept of independent aggregator is used to describe market parties that operate in some form independent from the supplier and BRP that already serve the prosumer. This means that multiple market parties could serve the same prosumer and that the aggregator is able to provide flexibility options to the prosumer while existing electricity supply and BRP arrangements stay intact. However, it is questionable what degree of independence these aggregators really have. Aggregators operating flexibility options at the prosumer will influence the operation of the supplier and BRP. Arrangements can be created to control or compensate this influence, but this requires very detailed and specific market rules. In this thesis it is deliberately decided to not label specific type of aggregators as independent aggregators. The concept of independent can give the impression that aggregators can fully operate independent from other market parties without contractual arrangements among market parties or legislative regulations that regulate this interaction. The results of this thesis show that various market parties are presently operating an aggregator model where they not fulfil a supplier or BRP role. However, it is also shown that these types of aggregators are involved in considerable complex contractual arrangements, especially the delegated/broker model. This shows that this element of independence is highly complex. Reflecting on different parts of this study, it is important to highlight that the independent aggregator should not be interpreted as the exclusive or vital instrument to unlock and create new sources of flexibility. This thesis shows that many different forms of the aggregator can provide flexibility to the electricity system.

Several aggregator companies are briefly described in chapter 7, aggregator value propositions and value capture. These aggregator companies have been described to demonstrate differences in the value proposition of aggregators and to describe what business opportunities are currently present. These cases should be interpreted as examples and this thesis does not provide an exhaustive overview of all aggregators that are participating in the Dutch electricity market.

This thesis shows that industry and technology trends are strengthening the development of different aggregator forms. Industry and technology trends have been discussed as two separate matters, while the combination and alignment of industry and technology trends is essential. Technological developments like digitalization create new opportunities, but these technologies cannot be utilized to the full extent if the industry, like regulation that facilities specific models or business models, follows these tech trends. The proposed new EU Electricity Directive creates regulation that allows and aligns with recent and upcoming technological developments and makes sure that technological advancements can be utilized in new business models. This directive will have a significant impact on the future development of the aggregator, as explicit rules and procedures regarding the aggregator's operation are formulated. Reflecting on this, it becomes apparent that aligning regulation with technological advancements and political choices about regulation have a considerable effect on the future development of the aggregator.

10.2 Implications for market parties

A good understanding of the aggregator concept is essential for market parties to identify the opportunities and threats that are relevant to them. The results of this study assist market parties in determining if the aggregator concept is a business opportunity or a threat. This research provides an overview of the current position of aggregators and an outlook into the future. The aggregator typology shows that different models of the aggregator can be adopted by market parties.

Many developments regarding aggregators are currently taking place and it is recommended for all actors in the electricity system to investigate and monitor these developments. Empirical evidence shows that there are currently aggregator business opportunities and that value is created and captured by aggregators. It is recommended for market parties to analyse if participating in aggregator activities is of interest to them. Additionally, the threat of aggregator activities on the current operation of market parties should be investigated as industry and technology trends indicate that aggregators may become more prominent in the future.

10.3 Implications for policymakers

This study provides insights into the aggregator and how they provide flexibility to support the electricity system. The concept of aggregators presents a new actor, a formal role and function that could provide flexibility. Results of this study show that developing and facilitating this aggregator concept should not be an end in itself. Our electricity system needs flexibility to cope with increasing amounts of electricity generated from renewables. There is a need to unlock new sources of flexibility and to create novel ways to accomplish this. The aggregator concept should be interpreted as one of the instrument that assists in achieving this and not as an end in itself.

The results of this study show that currently various aggregator models are adopted by market parties that operate in the Dutch market. Market participation of aggregators is already facilitated in various ways. Furthermore, industry and technology trends show that aggregators participation may become greater in the future. For policymakers it is important to realize that the aggregator concept is already operated by various market parties in the Netherlands. The aggregator is a novel concept that is not matured in its full extent, but business opportunities are being explored and exploited. This should be kept in mind when new policy is created to stimulate the market to create flexibility.

This research provides an overview of the current situation of the aggregator concept in the Netherlands. Furthermore, insights on the development of the aggregator in the future are provided. This provides arguments for policymakers in the discussion about revising policy or creating additional policy to facilitate aggregators in the electricity market.

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Appendix A

Overview of the Dutch electricity system

A.1 Liberalization of the electricity system in the Netherlands

The liberalization of the Dutch electricity system started in the mid-1990s when restructuring of the energy system dominated EU wide energy policy (van Damme, 2005). The Netherlands has been one of the frontrunners in the liberalization process of the electricity system (Verbong & Geels, 2007). Market mechanism were introduced to make sure the electricity system is efficient, competitive and would develop towards a sustainable energy market (Tanrisever et al., 2015). This liberalization resulted eventually in the system that is currently in place and formed the fundamentals of how flexibility is organized in the Dutch electricity system.

With the in 1998 adopted Dutch Electricity Act the electricity system changed drastically. It started the separation of electricity generation and distribution. Previously, vertically integrated utility companies owned both electricity production assets and the distribution grid. The liberalization related Directives (i.e. 96/92/EC; 2003/54/EC; 2009/72/EC) of the EU stated that 'unbundling' (i.e. *"the separation of the market functions traditionally provided by a single utility into functionally independent parts"* (Tanrisever et al., 2015, p. 2)) would enhance competition and provide more freedom for individual customers and suppliers with procurement and sales of electricity. In parallel with unbundling, competition was stimulated in the wholesale market. Liberalization started with opening the market for large electricity users and completed in 2004 with gaining access to all consumers to choose their electricity supplier freely (van Damme, 2005).

A.2 Structure of the electricity system

The structure and organization of actors and responsibilities is a crucial element of the market design. Boisseleau (2004) describes the market structure as the first level of his theoretical framework, as described in the theory section. In line with this framework the structure of the Dutch electricity system is further explained.

The structure of the Dutch electricity system has changed since the unbundling of generation from transmission and distribution in 1998. Figure 25 describes the structure of how the electricity system is organized in the Netherlands. De Vries et al. (2012) made a conceptual framework of the working principles of the Dutch electricity market. This model describes the system accurately and makes a distinction between the physical and institutional dimensions. The physical layer consists of technical aspects, like how electricity is flowing. The institutional layer consists of actors and institutions that construct the financial and organizational arrangements

The physical layer can be decomposed in the following dimensions:

Generation: Electricity is generated by electricity producers. The electricity producer is an important actor, as it has responsible of the asset that is producing electricity.

Transmission network: Traditionally, the majority of electricity is being produced by central power plants. These plants are directly connected to the high voltage transmission network, so large amount of electricity can be transported. The transmission network in the Netherlands is operated and maintained by TenneT. This network is defined as all cables and lines with a voltage of 110kV or higher (ACM, 2017b). Secondly, TenneT has the responsibility of system operations in the Netherlands, which will be described in more detail below.

Distribution network: The transmission network is connected to the distribution grid. The distribution grid is distributing the power to connections of small consumers. The distribution grid operator (DSO) is the responsible actor for the distribution network.

Load or consumption: Finally, the electricity will be consumed. The load can be of a small consumer (e.g. household), but could also be of a large consumer (e.g. industrial facility). Large consumers do not necessary have to be connected to the distribution network. Due to the large flows of electricity they can be directly connected to the transmission network.

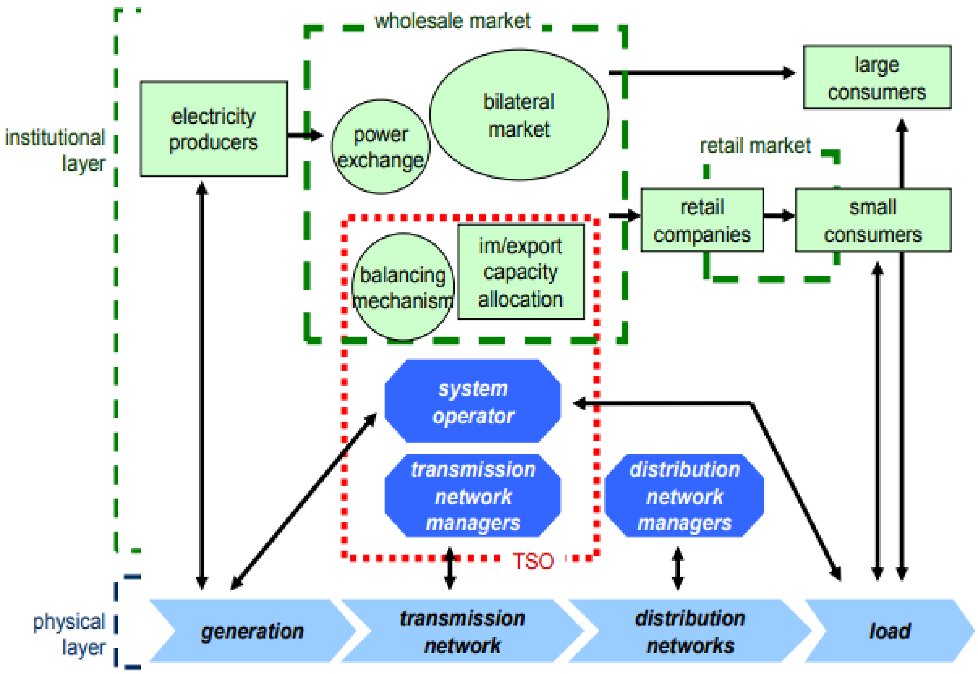

Figure 25 Organization of the electricity system in the Netherlands (de Vries et al., 2012)

Next to the physical layer there is an institutional layer, which consists of actors and institutions. This system describes how the economic value of electricity is being transported and who takes ownership of this value.

Electricity producers: The electricity producers have one or multiple assets that produce electricity. Production of electricity bears responsibilities. They have responsibility of forecasting and communicating their scheduled generation of electricity. This program responsibility is described in a later section.

Power exchanges and bilateral markets (wholesale market): The power exchanges and bilateral markets form the wholesale market. The wholesale market is the main marketplace where electricity is being traded between buyers and suppliers of electricity. The EPEX spot market is the main power exchange in the Netherlands. Bilateral trading or over-the-counter trading (OTC) happens directly between two traders.

Retail companies: Retail companies are selling electricity to the small end-user of electricity. The customers are mainly households and small commercial organizations. Since the liberalization in the Netherlands, small consumers are able to choose and/or change their retailer freely.

The main actors in the Dutch electricity system have been described. However, the role and function of some important actors needs more explanation. This will be discussed in the following sections.

A.2.1 Transmission and distribution system operator

The electricity grid is operated and maintained by both transmission and distribution system operators. There is only one transmission system operator (TSO) in the Netherlands which is the state-owned company TenneT. The TSO operates and maintains the transmission network, which is categorized as the high voltages lines and cables of 380kV till 110kV (ACM, 2017b). There are also several regional distribution system operators (DSOs) in the Netherlands, they are responsible for the distribution grid, which is defined as everything below 110kV until the connection at customer. The TSO and DSOs are natural monopolies and therefore they are heavily regulated (ACM, 2017b).

The TSO in the Netherlands, TenneT, has the responsibility for keeping the system in balance. TenneT ensures system balance by putting some requirements on market participants. TenneT requires two sets of information from market participants, a T-prognosis and an E-program. The T-prognosis is the forecasted transmission volumes or transmission capacity required for the supply or production of electricity (TenneT, n.d.). TenneT needs to receive these forecast one day in advance so they can ensure the safety and efficiency of the transmission of electricity.
The System code of the Dutch Electricity Act states that every connection needs to submit one day in advance an energy program (E-program) (ACM, 2015b). The E-program specifies the forecasted generation and consumption transactions for every 15 minutes (program time unit, PTU). The parties that are responsible for this E-program are called balance responsible parties (BRPs). TenneT needs the E-programs to ensure that demand and supply of electricity is balanced on the grid. The programs are also used to calculate and settle imbalance positions after the operational day (TenneT, 2000).

A.2.2 Balance responsible party

The balance responsible party (BRP) is also known as the program responsible party (PRP) or "Programma verantwoordelijke" (PV) in Dutch. This legal entity bears the responsibility of at least one physical grid connection and corresponds with TenneT (ACM, 2015b). The BRP is responsible for the forecast of the net demand (i.e. the difference between supply and demand through the physical connection), which is presented in the E-program. This E-program contains the forecasts for every imbalance settlement period (ISP). Currently, the ISP is 15 minutes in the Netherlands (TenneT, 2000). The responsibility of submitting an E-program of a connection can be passed on to a third party, who then bears the responsibility and will act as the BRP. There are two types of BRPs: full-BRP and trading-BRP (ACM, 2015b). The full-BRPs are allowed to take over responsibilities of other parties, while the trading-BRPs are only allowed to manage trading transactions. BRPs that submit the legally binding E-programs are ratified by TenneT and used for the settlement of imbalances. Imbalances are differences between the realized demand and/or generation from the forecasted demand and generation that has been submitted to TenneT in the E-program. BRPs are responsible for matching the forecasted E-program with the realized consumption and generation. Imbalances could be solved firstly by the BRPs themselves, changing their position (e.g. adjusting generation and or load). Otherwise, TenneT will activate the necessary balancing services to match demand and supply (ACM, 2015b). Activation of balancing services by TenneT will result in costs for the BRP. The imbalance cost of the BRP deviating from the E-program is calculated by TenneT and are settled with the BRP. The imbalance cost depends on the amount of deviation and the current market price of electricity at that moment of imbalance. Lastly, the BRPs are responsible for the exchange of measuring information (i.e. data of the exchange of actual generation and/or consumption at the connection) to TenneT. This measuring data, combined with the E-program and other information from TenneT will be used for the settlement of imbalances.

A.2.3 Balance service provider

In 2017 the European Balancing Guideline (EBGL) has been established by the European Commission (2017). This guideline establishes an EU-wide set of technical, operational and market rules to govern the functioning of electricity balancing markets. The guideline introduces the balance service provider (BSP) role. The BSP is a market participant providing balancing services to the TSO (e.g FCR, aFRR or mFRR). TenneT (2017a) is currently working on the implementation of the EBGL and the BSP role.

A.2.4 Electricity consumer and/or producer (prosumer)

The electricity consumer is changing due to the introduction of distributed energy resources (DER), like solar PV. DER make it increasingly feasible for small consumers to produce their own electricity. Traditionally, consumers obtained their electricity from the distribution grid, as can be seen on the left side of figure 26. In such an electricity system electricity flows are unidirectional, from the high voltage transmission grid to the loads that are connected to the distribution grid (Sweco et al., 2015). However, distributed generation (DG) and DER result in high shares of electricity generation at the distribution level. Electricity consumers that also produce electricity (prosumers) generate electricity for self-consumption and excess electricity could flow into the electricity grid, right side of figure 26. Electricity could be withdrawn from the grid at moments of low production of DER. This implies bi-directional flows between distribution and transmission systems, since distribution grids will export power at times when local generation exceeds consumption.

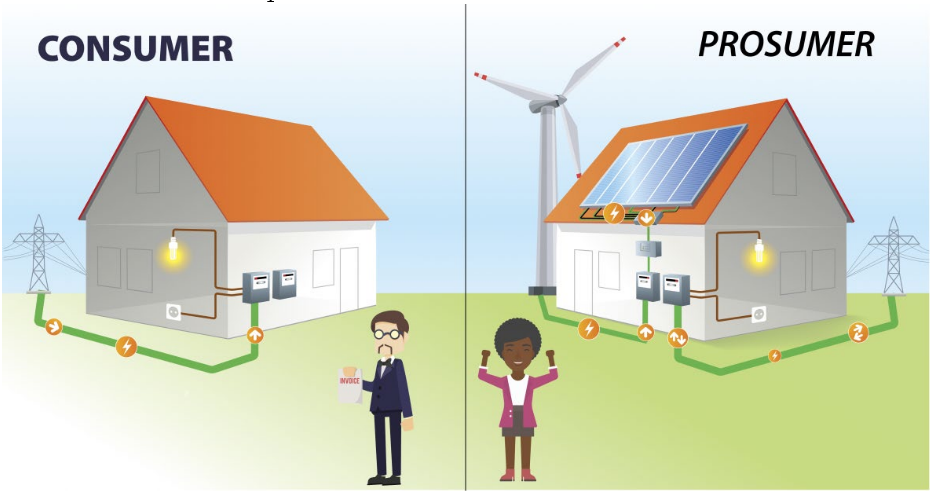

Figure 26 Difference between consumer and prosumer (Christopher, 2017)

Hence, the physical flows of electricity are changing, but this has also an impact on the functioning of the market design. The prosumer poses significant challenges for the market design at institutional, economic and social dimensions. Parag and Sovacool (2016) described extensively the impact of prosumers on the electricity market and the complexity that it imposes.

A.3 The electricity wholesale market

Electricity and thus flexibility can be traded on different markets. The second level of the theoretical framework of Boisseleau (2004) contains the wholesale markets. The Dutch electricity wholesale market will be discussed in this section.

The Dutch electricity wholesale markets can be segmented in five segments, from long-term to the imbalance market. Figure 27 provides an overview of the structure of these different markets.

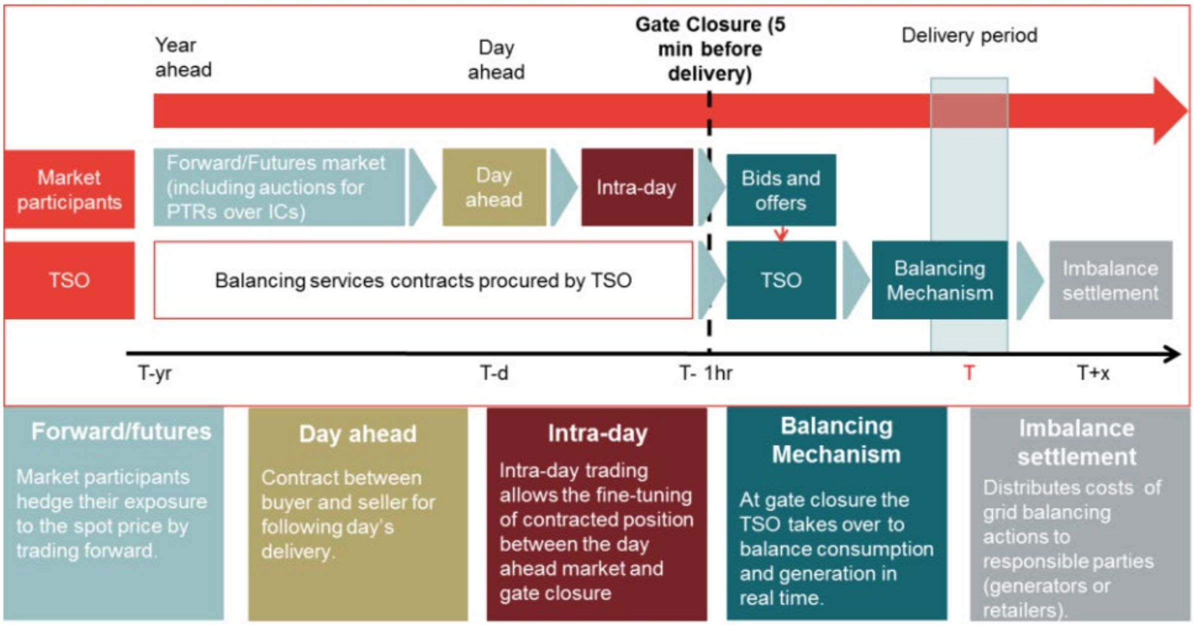

Figure 27 Overview of the different electricity markets in the Netherlands (Frontier Economiccs, 2015)

The electricity markets can be segmented in the time until delivery, with the long-term market far away from the delivery period and imbalance market close to delivery (or even after delivery). Electricity markets are organized into geographical areas, the so called bidding zones (TenneT, 2018f). The geographical area of the Netherlands forms the NL bidding zone. The NL bidding zone is organized as a 'copper plate', which means that electricity can exchange ownership freely without having to buy transmission rights.

Capacity market

The capacity market is a mechanism to encourage sufficient investments in reliable capacity to secure future supplies of electricity (Hogan, 2005). Capacity markets or capacity mechanisms reward the availability of generation capacity. Several different sorts of capacity markets are in place Italy, France, UK and other EU member states (EPRS, 2017).

The electricity market in the Netherland is based on the energy-only principle which implicates that payments are only made for energy and not for capacity, with the expectation of the balancing products that do receive a price solely for the provide capacity (Cramton, 2017). The energy-only principle of the Dutch electricity market design makes that there is currently no capacity market present in the Netherlands, aside from some capacity priced balancing products.

Forward/futures market

The forward, long-term or futures market is based on long-term agreements long before moment of delivery. The benefit of long-term arrangements is that they offer BRP security, clarity on the returns for investors and certainty on prices for the long term (TenneT, 2018f). The ICE ENDEX exchange is a market platform where futures for the delivery of electricity are being traded. There are many different contracts, with a variety of standardized products for the delivery of electricity for different durations. Long-term agreements are often also made without any intermediary. These over the counter (OTC) trades can be with other BRPs, producers or traders. However, long-term agreements are also often made within a BRP's portfolio. The forward and futures market span the time intervals from years before up to the day before delivery.

Day ahead market

In the day ahead market, electricity is being traded one day before delivery. In this market the largest volume of electricity is being traded, this market has also the highest number of participations (TenneT, 2018f). The EPEX day-ahead market is a platform where market parties can buy/sell electricity for next day delivery (EPEX SPOT SE, 2016). The EPEX day-ahead market is a blind auction, which means that buyers and sellers submit anonymous bids with prices and quantities on an hourly basis. The market opens 45 days ahead and closes one day before delivery at noon (12:00). After closing, an algorithm takes all bids and uses the physical constraints (national and international transmission capacity) to come with the clearance price. This clearance price is calculated with the use of the EUPHEMIA algorithm, which maximizes the social welfare while taking the market and network constraints into account, the document of EPEX Spot et al. (2013) provides a detailed explanation of this process.

Intraday market

The day-ahead prices are made publicly available after closure of the day-ahead market (noon at the day before delivery). However, the physical delivery of electricity is still hours away after closure of the day-ahead market. The intraday market is established to trade electricity in this time window until 5 minutes before physical delivery (EPEX SPOT SE, 2016). Final adjustments can be made between the amount of electricity bought and exact demand or between the amount of electricity already sold and exact generation. Hourly contracts for the next day are available from 14.00 at the day before delivery and 15 minutes contracts open at 16.00 at the day before delivery. Intraday markets are mainly used for (EPEX SPOT SE, 2016):

- adjusting positions based on the results of the day-ahead auction
- optimizing the running and planning of power generation
- managing forecast errors and/or unforeseen events
- adjusting from hourly positions to 15 minutes
- offering flexible generation as a substitute for renewables

Balancing markets

Supply and demand of electricity need to be continuously in balance. Primary, the responsibility of energy balance is covered through balance responsible parties (BRPs). However, the TSO, has the final responsibility to keep the grid in balance. TenneT needs to be able to cope with imbalance situations that were not solved by BRPs. Therefore, TenneT regulates the electricity market after gate closure to ensure the balance on the grid. This is called the balancing market and starts at gate closure; several mechanisms are at the disposal of TenneT.

Balancing ancillary services

The TSO must ensure that there are market parties that are willing to buy electricity if there is a surplus on the grid, and producers that could generate additional amounts of electricity when there is a shortage of electricity. In the Netherlands, this is mainly done by auctioning balancing ancillary service products. Several products with different technical specifications have been constructed and market parties, which are called balance service providers (BSPs), can provide these products on a commercial basis.

The products are characterized as follow:

- **FCR – Frequency Containment Reserves**. The purpose of FCR is to limit and stabilise frequency disruptions. This is done based on an automated response within 30 seconds when frequency derivations occur (TenneT, 2017b). Assets that provide FCR are using a frequency meter to control the delivery of FCR. This is the first kind of product that reacts to imbalances.
- **aFRR – automatic Frequency Restoration Reserves**. aFRR is used to correct real-time power imbalances (TenneT, 2018d). aFRR is activated automatically by TenneT sending setpoints to the BSPs on a real-time basis.

- **mFRR – manual Frequency Restoration Reserves**. This kind of reserves is used for large-scale and unexpected long-lasting imbalances. mFRR is activated manually, directly as mFRRda or scheduled as mFRRsa. TenneT activates mFRR if the available capacity of aFRR falls below certain thresholds until the moment that sufficient aFRR becomes available (TenneT, 2018d)

The above-stated balancing products are sourced before gate closure to ensure that enough standby capacity is available in case it is needed. Auctions of these products are often based on availability for a week or month (TenneT, 2018g). Commonly there is first a capacity auction to contract a minimum amount of capacity to ensure enough bids for every ISP are being made. The winner of this capacity auction has the obligation to bid a marginal energy price for activation of the auctioned capacity. Some products (e.g. mFRR) allow it to make so-called 'free bids' (TenneT, 2000). This means that market parties that did not win the capacity auction can bid their marginal energy price. The aggregated marginal energy bids from the market parties that won the capacity auction and the free-bids form a bid ladder. This bid ladder is used to activate reserve capacity from the bid with the lowest marginal price.

Voluntary balancing contribution

In the Netherlands, there is another mechanism developed to ensure a balanced grid, voluntary contribution. TenneT publishes almost real-time balancing information (i.e. an indication of imbalance prices and activated quantities) (TenneT, 2000). This near real-time information provides economic incentives that enable BRPs or other market parties to assist balancing the grid. BRPs submit an E-program to communicate the scheduled generation and off-take of electricity within the portfolio of assets under their control. BRPs can deviate from this E-program to assist balancing the grid. BRPs that adjust their portfolio in such a way that this alleviates imbalance will gain financial compensation. The BRP needs to pay a financial compensation if the portfolio position is contributing to imbalance.

Appendix B

Interview guide

Introduction - (5 minutes)

- Briefly introduce myself and my research project

The scope of my thesis is analysing aggregators in the Dutch electricity market and I'm focussing on two aspects:

1. The position and possibilities of aggregators in the current Dutch electricity market. For this I'm studying what is currently possible and what is currently done by aggregators. Secondly, I'm examining the value creation and value proposition of aggregators that provide flexibility.

2. The possible function and role of aggregators in the future Dutch electricity system. I'm trying to find relevant market design aspects and other trends that could influence the facilitation of aggregators in the future Dutch electricity system.

- Could you briefly describe your company/organization and what your role is within this company?

Flexibility (Currently and Future) – (5minutes)

1. How flexible would you define the current electricity system in the Netherlands?
2. From your perspective, do you think this will change in the upcoming years, if so how and when?

Define Aggregator – (10 minutes)

1. How would you describe an aggregator?
2. From your perspective, what is the purpose and function of an aggregator?
3. Who do you think is currently fulfilling the role of aggregator?
4. How is your company affiliated with aggregators?

Electricity market design and aggregators – (10 minutes)

1. How is in your opinion the current Dutch electricity market design facilitating aggregators?
2. What is the best market design element that facilitates aggregators?
3. What is the worst market design element related to aggregators?
4. From your point of view, which type of aggregator do you think is best facilitated by the current Dutch electricity market design? (Rank table 1) Could you elaborate on your reasoning?

Current possibilities for Aggregators – (15 minutes)

1. What are the current possibilities for aggregators in the Netherlands?
2. What do you see as currently being done by aggregators?
3. In your opinion, what is the added value of aggregators?
4. What value proposition can aggregators deliver to different stakeholders?
5. Which market is currently most appropriate for aggregators to participate? (Ranking table 2) Could you elaborate on this?

Future and Aggregators – (10 minutes)

1. What will be in your opinion the role of aggregators in the future?
2. What kind of developments do you expect in the function and role of aggregators?
3. Do you think the concept of aggregators is permanent/durable?
4. From your perspective, which market is most appropriate for aggregators to participate in the future (i.e. in 2030) and why? (Ranking table 3)
5. In your perspective, what type of aggregator is best facilitated by the future Dutch electricity system (i.e. in 2030)? (Ranking table 4)

Practices outside the Netherlands – (5 minutes)

1. Do you see elements in the market design of other EU countries that are successfully facilitating aggregators, and which may be relevant for the Netherlands?
2. Do you see practices of aggregators abroad which may not possible (yet) in the NL but could be relevant for the Netherlands?
3. Have you heard about any other relevant market design element for facilitating aggregators?

Closure

Thank you for participation. Do you have any additional insight that you like to share? We will keep in contact for the results of my research.

Rank table 1

Which type of aggregator is best facilitated by the Dutch electricity market design? (1= best, 5=worst)

Type	Rank-Current	Rank – 2030
Combined aggregator-supplier		
Combined aggregator-BRP		
Aggregator as service provider		
Delegated/Broker Aggregator		
Prosumer as Aggregator		

Rank table 2

Which market is most appropriate for aggregators to participate? (1= best, 6=worst)

Market	Rank-Current	Rank-2030
Day-ahead wholesale market		
Intraday wholesale market		
BRP-portfolio optimization		
TSO Balancing Ancillary services (FCR, aFRR, mFRR)		
Congestion management (TSO/DSO level)		
Capacity market		

Appendix C

Informed consent form

Researcher	Jesper Juffermans
Organization	Eindhoven University of Technology
Project	Master thesis Innovation Sciences
E-mail address	
Telephone	

Thank you for agreeing to participate in this study. This form details the purpose of this study, a description of the involvement required and your rights as a participant.

This interview will be used in the research that I am doing to obtain the degree of Master of Sciences for my study Innovation Sciences at the Eindhoven University of Technology.

As part of my education, I am writing a thesis about the developments of aggregators in the Dutch electricity market. You are kindly being requested to participate in this study due to your expertise in the topic of aggregators.
The purpose of this study is:

- To gain insights into the possibilities and developments of aggregators in the Dutch electricity system, and to get a better understanding of the possible future role of aggregators in the Dutch electricity system.

The benefits of this research include:

- To better understand the functioning of aggregators in the Netherlands
- To identify developments that could assist in better facilitating aggregators

Your participation in the study will involve an interview with an estimated length of one hour. Your name will be kept confidential, but your position and name of organization may be used to clarify relevant insights from this interview. Direct quotation from the interview may be used in this study, but will not include personal information. In case of direct quotation, Interviewee will be contacted to verify that facts and quotes are accurate.

This interview will be recorded on an audio-recorder to help me document your insights in my own words. The recording will only be heard by me for the purpose of this study and will be destroyed after the interview has been transcribed.

You have the right to withdraw from the study at any time. In case you choose to withdraw from the study, all your information (including recordings) will be destroyed and will not be included in the research.

You are encouraged to ask questions or raise concerns at any time about the research, method or questions that I am asking. Please feel free to contact me at any time at contact details listed above.

The outcome of this study will be a research report. If you wish, this report can be sent to you after the completion of the study, which is expected to be October 2018. In order to receive the research report, please leave your e-mail address at the bottom of this page

By signing below, I acknowledge that I, ___________________________________ have read and understand the above information and agree to participate in this study

Date: _________________________

Signature interviewee: _____________________

Signature Jesper Juffermans: _____________________

Appendix D

Interview participants

Not publicly available

TU/e Technische Universiteit Eindhoven University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

Declaration concerning the TU/e Code of Scientific Conduct for the Master's/PDEng/PhD thesis

I have read the TU/e Code of Scientific Conduct[1].
I hereby declare that my Master's/PDEng/PhD-thesis has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct

Date
22-11-2018

Name
J.K. (JEROEN) JUFFERMANS

ID-nr
0824543

Signature
....

[1] See: http://www.tue.nl/en/university/about-the-university/integrity/scientific-integrity/
The Netherlands Code of Conduct for Academic Practice of the VSNU can be found here also. More information about scientific integrity is published on the websites of TU/e and VSNU.