The implications of unlocking decentralised prosumer flexibility

A comparative analysis of the intermediary aggregator vs. blockchain technology by considering a system integration perspective

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A comparative analysis of the intermediary aggregator vs. blockchain technology by considering a system integration perspective

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Preface

Prior to my thesis I couldn't guess that I would end up with a thesis related to blockchain technology. I had heard of Bitcoin, the insane high volatility of the Bitcoin currency, the fact that Bitcoin has the ability to disrupt the banking industry and that blockchain was the underlying technology of this new artefact. However, I didn't know of the functionalities of blockchain behind Bitcoin and other cryptocurrencies. On one day Mirjam de Boer, my EY supervisor, asked me to do research on the possibilities for blockchain technology to take over a specific business process for an EY client. Browsing the blockchain Wikipedia page, probably one of the most complex existing Wikipedia pages, I started my blockchain journey. Giving blockchain technology a detailed read I considered the opportunities it could have behind cryptocurrencies. At that specific moment my preliminary research proposal was focussed on the detailed design of the role of the aggregator. Considering blockchain technology and its expected impact of disintermediation was completely at odds with the design of the aggregator. After discussing the opportunities of blockchain with my graduation committee it was decided to place the aggregator role and blockchain technology against each other to find out which systems was expected to have a better fit within the electricity sector.

" In this paper, we propose a solution to the double-spending problem using a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions". With this sentence Satoshi Nakamoto, or whatever his real name may be, concluded his introduction of his/her Bitcoin whitepaper. During this thesis I often wondered whether Nakamoto realised how big the impact of his Bitcoin whitepaper would be. Nine years later we find ourselves in a time where blockchain is a major hype and Bitcoin, and other cryptocurrencies, keep increasing in popularity and value. The blockchain hype even led to the emergence of 'the blockchain club', a group of students from the faculty Technology, Policy and Management graduating in the field of blockchain technology. Currently, the development of blockchain technology and its applications happen at unprecedented speed. Since the introduction of smart contracts with platforms such as Ethereum and Hyperledger Fabric extending on the technology of the Bitcoin blockchain we already speak of blockchain 2.0. Ironically, many corporate companies, the parties where Nakamoto seemed to rebel against, are now looking into how blockchain can gain efficiencies in their business.

Performing this research made me enthusiastic about blockchain and learned me to nuance the potential of blockchain technology at the same time. In my many hours spent on the internet, and by executing this research, I found both really useful blockchain use case, but also many implications to the usage of blockchain technology. During my thesis a person told me '*once you can replace the word blockchain with database in arguing why blockchain should be implemented in a specific use case, just stick with the database'*. It is therefore important to assess every individual use case whether blockchain could play a role. Only time will reveal whether this technology should be considered as an overhyped bubble or whether it is actually going to be adapted by society and can be described as the fourth industrial evolution.

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Acknowledgements

With this thesis I conclude my journey in Delft, Delft University of Technology and more specifically my wonderful time at the faculty of Technology, Policy and Management where I felt at home from the very beginning. Executing this research was not possible without the extensive support of some people. In this section I'd like to express my gratitude to those who provided me with their support.

At first, I deeply thank Daniel Scholten to be my first supervisor. From the very beginning, even whilst doing my literature review in the Thesis Project Definition, a pre-required course to execute this thesis, Daniel was available for feedback and support. He helped me in setting up and structuring this research and provided me with any feedback when necessary. For me, our relationship felt more like a colleague relationship rather than a supervisor – student relationship. So I want to thank Daniel for his substantive support, fast e-mail replies and our many private discussions.

I also want to thank Émile Chappin for his feedback and support as a second supervisor. I first got to know Émile during his supervision of a second year course project. Because of his substantive support and feedback I asked Émile to supervise me during my Bachelor Thesis Project where he pushed me to a maximum performance, leading to both a high grade and a publication. Because of his critical view and his substantive support I soon knew that I wanted to include Émile in my graduation committee for my Master Thesis.

The last person of my graduation committee is Rolf Künneke. Rolf's feedback as a chair of my committee was very useful and detailed in structuring and setting-up my research during my kick-of- and mid-term meeting. Besides he provided me with substantive feedback at my greenlight meeting.

I also want to thank EY Advisory for the opportunity they offered me to execute my research within EY. More specifically, I want to thank the Strategy & Customer team where I was situated in. They offered me the opportunity to work on my research and supporting in real-life projects in a balanced way. I want to thank Mirjam de Boer-Postmus in special. She gave me both the freedom and support to perform my research. Besides, she offered me the opportunity to work with her on real-life Power & Utilities projects. The highlight for me was supporting a Proof of Concept of a blockchain application for a Dutch utility.

Next to my supervisors I want to thank the 10 interviewees who made time in their busy agenda's (varying from 1 hour up to 2.5 hours!) for helping me graduate. Many thanks to Cherrelle Eid, Theo Fens, Richard van Gemert, Sjors Hijgenaar, Jeroen de Joode, Machiel Mulder, Roelof Reineman, Guy Rutten, Jeroen Scheer and Leon Straathof for your contribution.

Last but not least, I want to thank my family and friends. My parents provided me with the financial and mental support I needed in my journey to become an engineer. They founded the basis which helped me to get me in the position where I stand now. Also important is the relationship with my brother since we always push each other to achieve the maximum possible. I want to thank my friends to listen to my endless stories why blockchain technology is such a cool technology and for those who have knowledge of blockchain technology, thank you for the triggering discussions. I also want to thank my friends for the necessary distraction which I definitely needed in executing this research. A special thanks to my roommate and friend Maurits van den Hoven which provided me with support by being my reviewer at the end of this research.

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Executive summary

To maintain electricity grid reliability in the presence of a large amount of intermittent variable renewable energy sources the electricity grid is in need of flexibility. The expected increase of prosumer activity in decentral electricity- generation and storage, provides an opportunity in providing flexibility from a decentralised level. Flexibility from the prosumer can be provided by controllable loads, local generation, electricity storage and adaptive EV charging and can serve roughly three market services: portfolio optimisation for balancing responsible parties (BRPs), grid- and congestion management for the DSO, and balance services for the TSO.

A way of organising decentralised flexibility is the introduction of the aggregator role, a central party providing market intermediation between prosumers and market parties by the functions of information management, bundling of service, matching and market clearing and transaction guaranteeing. The aggregator is characterised by contractual formalised relationships, central control, and the connection with the central national wholesale model. Another way of organising a model of decentralised flexibility is by means of a blockchain application. Blockchain is an innovative disrupting technology enabling the disintermediation of market structures and organisational institutions. With the introduction of a transactional system on a distributed ledger that is immutable, unalterable and highly secured, it is expected that the intermediation of a trusted third party (such as the aggregator) is superfluous. Blockchain is characterised by automatic coordinated, and executed transactions based on smart contract logic that enables automatic matching of suppliers and consumers of flexibility without intermediation. It is expected that the characteristics of blockchain ultimately lower transaction costs.

Because of the interwoven character of technology and institutions, it is very important to align both technology and institutions in designing the aggregator role and a blockchain application. It is however still unknown how a system integration perspective challenges the implementation of the aggregator or blockchain application. This research provides an analysis of system integration challenges for both the aggregator role and blockchain application that arise from the perspective of system integration. The following research question is formulated:

'What system integration challenges need to be overcome to enable the implementation of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?'

Design implications in this research are identified by analysing the system integrative fit of the aggregator role and blockchain application following the principles of the comprehensive design (CD) framework, a framework focussing on system integrative design of energy infrastructures. In the framework, the technical and institutional perspective of energy infrastructures are aligned along three design layers; access, responsibilities, and coordination.

System integrative design implications

This research identified many design implications for both the aggregator role and a blockchain application in unlocking decentralised flexibility. After initial analysis, design implications have been validated, complemented and iterated by means of expert interviews.

Aggregator

A model for decentralised flexibility operated by the aggregator is at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector. The role of the aggregator as market intermediary however fits current sector parties. Central steering

by the aggregator allow rules, roles and responsibilities to be assigned very specifically. This however implies a strong formalised relational environment causing a high degree of operation, and interaction complexity which is expected to induce significant transaction costs. At an coordination level, many implications in the operations and control of transactions are present.

Blockchain
The model for decentralised flexibility operated by a blockchain application is both at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector as well as with the role of current parties operating in the sector. Due to disintermediation it is very hard to assign specific roles, rules and responsibilities. Organising the blockchain in a private network typology, implementation of steering- and regulating mechanisms are possible. Private blockchains however opposes the potential of disintermediation and self-organisation. Because of the absence of full disintermediation, the question is to what extent the aggregator and blockchain actually differ in terms of organisation. In terms of coordination, blockchain is not in need for formalising relationships, making coordination less complex which is expected to have a positive effect on transaction costs. However, also in a blockchain application many coordination complications in the operations and control of transactions are present.

Design implication classification
Design implications as identified in this research have been classified in three categories, design implications that define the considerations in comparing both aggregation systems on different performance indicators, design implications that need to be resolved to enable the successful implementation of a flexibility model at a decentralised level, and design implications that need to be further elaborated in the detailed design. The first category refers to different implications of the aggregator role such as the possibility of assigning roles and responsibility in both systems and the complexity of coordination. The second category refers to current technical-, regulatory-, and market barriers in the electricity sector that hamper a flexibility model at a decentralised level. Finally, the third category refers to those implications that need to be resolved in future detailed design of the specific aggregation system.

Discussion and suggestions for future research
This research is a preliminary step for the detailed design of the aggregator role and blockchain application. It explored the system integrative fit of both the aggregator role and blockchain application in de Dutch electricity sector. As the analysis showed, blockchain might in this specific case not be able to provide for full disintermediation and self-organisation. Also discussed is the ability for a hybrid aggregator-blockchain model where the blockchain is the operationalisation of the aggregator role. The question is however whether blockchain can compete with current centralised database solutions. Considering the research results and the discussions above, suggestions for future research are:

- What specific policy design is needed to resolve for current barriers, for the operation of a decentralised flexibility model?
- What does a detailed design of the aggregator role, deploying decentralised flexibility incorporating system integration look like?
- What does a detailed design of a blockchain application, deploying decentralised flexibility incorporating system integration look like?
- What is the effect of blockchain technology on operational efficiency of the aggregator role in deploying decentralised flexibility compared to existing operational models?
- What could a blockchain assessment framework in the energy sector look like?

- How do aggregation systems of decentralised flexibility compare to other grid flexibility options, such as interconnection, large scale energy storage and dynamic network tariffs?

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List of definitions

Definition	Description
Flexibility	The ability of the electricity grid to cope with variability introduced by the increasing share of VRES.
Decentralised energy systems	Energy systems where distributed energy resources play a major role.
Prosumers	Consumers that consume, produce and store electricity.
Aggregation system	A technical system which bears the responsibility of aggregating the capacity of flexibility from multiple smaller storage units defined by a set of rules.
Aggregator aggregation system	An intermediary which centrally manages the aggregation of the capacity of flexibility from multiple smaller battery units by means of a virtual plant. It subsequently offers this flexibility as an aggregated load to interested parties such as BRPs, TSO and DSOs. The aggregator operates by the mandate of mutual contractual agreements.
Blockchain technology	A distributed database which records data of performed transactions in unalterable and chronologically linked blocks in a public ledger.
Blockchain aggregation system	A blockchain network which automatically performs the transaction of aggregating and offering of the capacity of flexibility from multiple smaller battery units by the operation of smart contracts.
Socio-technical systems	Systems in where engineering- and institutional sub-systems are heavily intertwined.
Engineering perspective	In the electricity sector, the engineering perspective refers to engineering systems related to the commodity flow in the supply chain, the tangible assets involved in the operation of the electricity sector.
Institutional perspective	In the electricity sector, institutional systems refer to the environment where economics is performed and influenced.
System integration	The perspective of designing new systems by simultaneously considering the engineering- and institutional perspective.
Design implications	Implications that are triggered by integrating a specific aggregation system in the environment of the Dutch electricity and implications within the current design environment of the Dutch electricity sector that challenges the ability to implement a specific aggregation system

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1 Introduction

1.1 The electricity sector in transition, a changing landscape

The electricity sector is subject to major changes in achieving a sustainable energy sector. The need for changes is caused by the growing scarcity of conventional fossil electricity resources such as coal and gas, the need for security of supply in a market with increasing demand, and the rising interest in environmental degradation caused by energy production (Dorian et al., 2006). A sustainable electricity sector refers to a variety of concepts. The World Energy Council's definition of a sustainable energy sector is built upon three dimensions; energy security, energy equity, and environmental sustainability (World Energy Council, 2017). Energy security refers to the reliability of the energy infrastructure, energy equity refers to the accessibility and affordability of energy, and environmental sustainability refers to the usage of low-carbon resources (World Energy Council, 2015).

In need for change, the European Union put regulation regarding renewable energy in effect to lower the dependency upon fossil fuels, meet the future European energy demand, and lower emissions caused by the production of electricity (European Commission, 2017d). Policy of the European Union regarding the renewable energy sector is defined in the Renewable Energy Directive of the EU (European Commission, 2017e). This directive contains targets of 20% greenhouse gas emission reduction (compared to 1990), 20% share of renewable energy sources, and 20% energy efficiency improvement by the year 2020 throughout the entire EU (European Commission, 2017a). Meanwhile, targets for 2020 have been redefined into targets for 2030 in the 2030 climate & energy framework. Targets for 2030 aim to cut greenhouse gas emissions with 40% (compared to 1990), increase the share of renewable energy to 27%, and have a 27% improvement in energy efficiency (European Commission, 2017b).

Despite the legally binding character of a directive, targets for the share of renewable energy vary among member states based on their starting point and total potential. Country specific targets are translated in National Action Plans by national governments of the European member states. The overall share of renewable energy for the Netherlands in 2020 is set at 14% (Ministry of Economic Affairs, 2016). The share of renewable energy sources in the electricity sector is projected at 37% for 2020 (Ministry of Economic Affairs, 2010). In the far future, the target of renewable energy is 16% in 2030 and almost 100% in 2050. Ultimately this should lead to a 95% CO_2 reduction in 2050 (Ministry of Economic Affairs, 2016).

1.2 Balancing the energy trilemma, the need for flexibility in a sustainable electricity sector

An increasing share of variable renewable energy sources (VRES) implies an increase in variability in power output and quality, hampering the reliability of the electricity grid (Kondziella & Bruckner, 2016). In maintaining energy security whilst facing an increase of variability in the electricity grid, both the transmission system operator (TSO) and the electricity distribution system operator (DSO) are in need of flexible resources to provide the electricity grid with flexibility (Bertsch et al., 2012). Several, though similar, definitions of flexibility or system flexibility can be found in the literature. Bertsch et al. (2012) state that "*flexibility is the capability to balance rapid changes in renewable generation and forecast errors within a power system*". Denholm and Hand (2011) state that "*System flexibility can be described as the general characteristic of the ability of the aggregated set of generators to respond to the* *variation and uncertainty in net load".* A third definition of flexibility is given by Lannoye et al. (2012), "*the ability of a system to deploy its resources to respond to changes in net load".*

A study conducted by CE Delft (2016) concluded that in total, the Netherlands is in need for 5 GW peak supply and 2.3 GW of flexible demand in 2023. The need for flexibility options in the electricity is acknowledged by Dutch policy makers, however, this didn't lead to concrete implementations yet. One of the ten pillars in the Dutch energy agreement on stimulating the energy transition is dedicated to reforming the current electricity infrastructure in providing flexibility options to the electricity grid (SER, 2013). A later government publication, on stimulating the energy transition, stated that the modification of the current electricity grid into a more robust flexible grid is considered as a central element in the transition of the Dutch electricity sector (Ministry of Economic Affairs, 2016).

1.3 Other trends in the evolving electricity sector

Many trends can observed in the continuously evolving power sector. Due to the rising increase of photovoltaic (PV) energy penetration, a trend towards more decentralised energy systems can be observed (Blaabjerg et al., 2006). Currently, the transmission- and distribution network and the configuration of activities in the Dutch electricity sector are optimised for a system with centrally based production assets. To be able to handle the increase of decentralised energy sources it is necessary to configure the transmission and distribution network in a way that both are able to handle the increase of decentralised electricity production in a reliable way. This is also elaborated on in the 'Energieagenda'. A noteworthy trend in power systems becoming more decentralised is that consumers tend to behave more and more as prosumers (Schleicher-Tappeser, 2012). Whereas consumers only consume electricity, prosumers behave very dynamic by consuming, but also producing, and storing electricity (Grijalva & Tariq, 2011). Prosumers therefore heavily influence the direction and intensity of electricity flows on the distribution grid, out of the control of the system operators. Both the increasing decentralisation and the emergence of prosumers cause more imbalances on the electricity grid and therefore increase the need for flexibility.

In future energy systems, usage of data in the electricity system will significantly increase (Ruester et al., 2013). The most tangible example of data usage in the Netherlands is the large scale roll-out of smart meters. The Dutch government strives to install a smart meter within every household before 2020 (RVO, 2016). The smart meter can digitally communicate information about real-time electricity usage to relevant parties such as the DSO or electricity producers (Hoenkamp et al., 2011). The main advantage of the smart meter corresponding to a sustainable energy sector is that the smart meter enables smart balancing of energy demand and energy production on different levels (Ons Energienet, 2017).

1.4 Decentralised flexibility and integration complexities

Due to the trend of decentralisation and the emergence of prosumers, an opportunity for using flexibility on the level of prosumers arises. This section elaborates on flexibility options that can be provided at a decentralised level.

1.4.1 Demand side management as flexibility option for the distribution grid

Flexibility from the prosumer to support the reliable operation on the distribution grid is also referred to demand side management (DSM) (Gellings, 1985). According to Gellings (1985), *"DSM is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e. changes in the time pattern and magnitude of utility's load".* Forms of DSM are peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape (see also Figure 1-1).

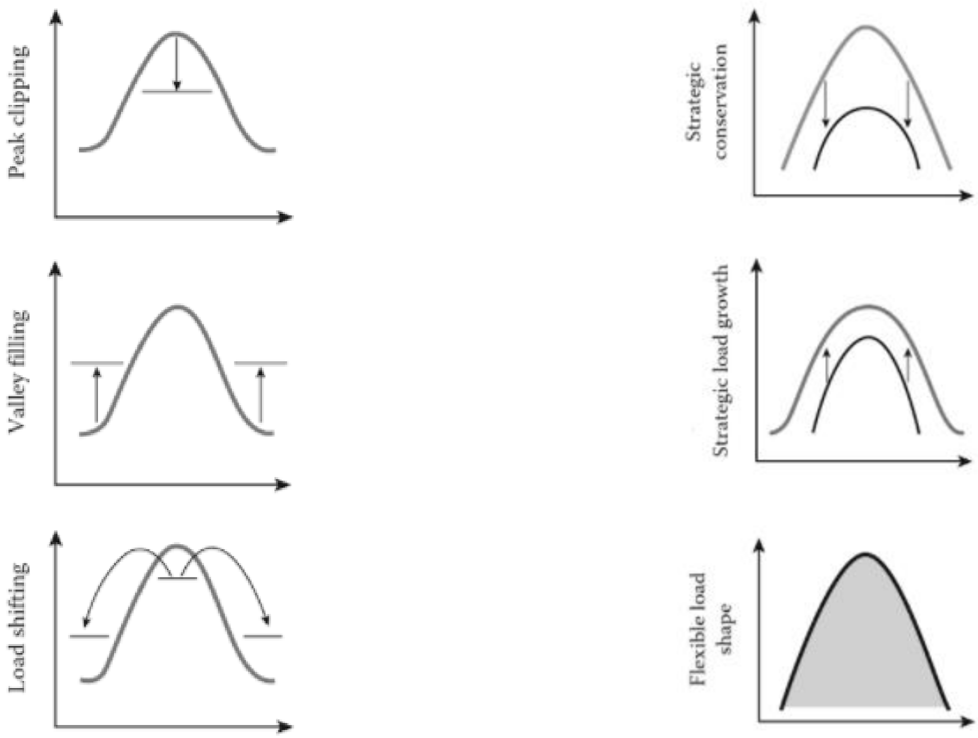

Figure 1-1: Forms of demand side management (abstracted from Gellings and Parmenter (2017))

Peak clipping is the reduction of system peak loads, valley filling comprises the filling of off-peak loads, load shifting is the shift of load from on-peak to off-peak periods, strategic conservation refers to load management at end-use consumption, strategic load growth is the load growth over time (such as electrification by electric vehicles) and flexible load shape refers to consumers adapting their load by incentives provided. USEF, an acknowledged framework in the management of flexibility at a decentralised level, distinguished four categories of applications cable to perform DSM activities; controllable load, local generation, storage and EVs. Controllable load are those loads that can be used for load shifting such as heat pumps, air conditioning and heating- and cooling processes. Local generation is variable power at the level of prosumer such as solar PV and micro-CHP systems. The storage category comprises residential storage units (mainly batteries such as the Tesla Power Wall). Finally, EV's can offer grid flexibility by smart- charging and de-charging of EV batteries (USEF, 2015). Decentralised flexibility is able to serve roughly 3 types of market services, congestion management for DSOs, portfolio optimisation for BRPs and balancing mechanisms for TenneT.

1.4.2 Complexities of decentralised flexibility

The integration of decentralised flexibility is prone to many barriers. Many complexities will arise relating to the operation of flexibility at a decentralised level. For example, a system which could control all active consuming and supplying loads is not developed yet. Another complexity is, that many of the flexibility offering loads only can offer a small amount of flexibility to the grid and therefore an individual unit only has a minor impact on grid performance. Besides, individual flexibility units are not able to cope with the minimum technical size requirement of Dutch balancing markets and ancillary services, which is 1 MW for Primary Reaction, 4 MW for Regulating Capacity, 4 MW for Reserve Capacity and 20 MW for Emergency Power respectively (SEDC, 2015). To have a significant effect on grid flexibility and to be able to trade small flexibility capacities from active loads, some sort of aggregation system is needed that enables the operation of a decentralised flexibility system (Eid et al., 2015). This can either be done by a market intermediary, from now on referred to as the aggregator, or by a blockchain application (the technical system behind the Bitcoin principle (Nakamoto, 2008)), which can be considered as an operating system enabling the aggregation of flexibility. In order to operate an aggregation system[1] , use of real-time and forecasting prosumer data is a must (Eid et al., 2015). The roll out of smart meters, as discussed in 1.3, offers a great window of opportunity to enable some sort of aggregation system.

1.5 The aggregator role

The operation of a future aggregator should comprise four functions; information management, bundling of services, matching and market clearing and the guarantee of transaction (Eid et al., 2015). A possible market positioning for the aggregator is conceptually shown in Figure 1-2.

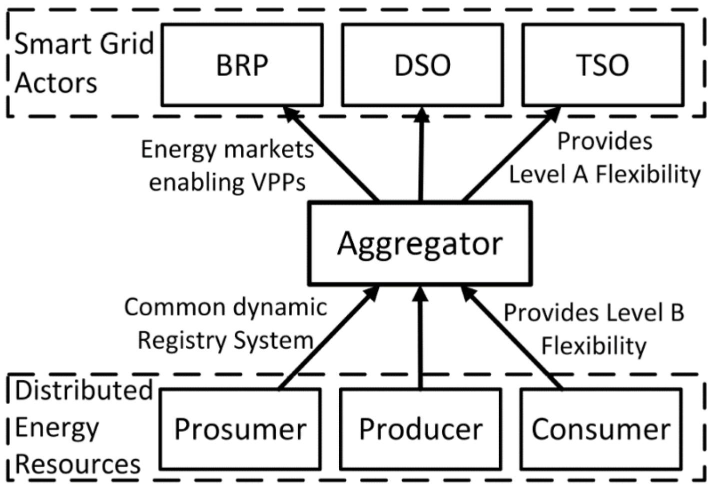

Figure 1-2: The aggregator, a central role in connecting decentralised flexibility with electricity markets (Dethlefs et al., 2015)

As seen in the figure, the aggregator acts as a middleman between decentralised electricity actors and smart grid actors. It collects Level B flexibility, flexibility that an individual prosumer can offer for example from its home- or car battery, to offer as Level A flexibility to the electricity market- and grid. Level A Flexibility in this case is offered in the grid by the concept of a virtual power plant (VPP) (Dethlefs et al., 2015). A VPP can be defined as the aggregation of multiple electricity sources (Bignucolo et al., 2006). The aggregator concept with a physical actor performing aggregation services induces many transaction and interaction complexities in the electricity system.

[1] A technical system which bears the responsibility of aggregating the capacity of flexibility from multiple smaller storage units defined by a set of rules. This doesn't refer to the physical aggregation of storage capacity per se, but to a system which can fulfil techno-operational and financial-economical functionalities in the enabling of a system that operates decentralised flexibility. In the remainder of this research, the aggregation system refers to both the system where a physical aggregator or blockchain application enables decentralised flexibility by using active controllable loads.

1.6 Blockchain as enabler for aggregation

Blockchain is a disruptive technology conceptualised by Nakamoto (2008) by the introduction of the Bitcoin cryptocurrency. Blockchain technology makes the interference of a third party, a market intermediary, obsolete (Nakamoto, 2008). In blockchain technology, a transaction is executed with just the consent of the two parties that are willing to perform a specific transaction. Data of the transaction performed is recorded in a public ledger which is available to the relevant actors of a specific network. The data records, also referred to as blocks, are stored in a distributed database. Blocks contain data and are shared, unalterable, linked with other preceding blocks and assigned with an unique timestamp. Since the information stored in the ledger is public to anyone in the system, blockchain is a distributed solution and perceived to be more transparent, secure and efficient compared to a transaction system where a third party interferes (Yli-Huumo et al., 2016).

Blockchain is more and more perceived as a technology which can play a major role in other sectors beyond the financial sector (C. Burger et al., 2016). Mortier (2017) notes tracking and tracing of energy production and consumption, automated network balancing, and energy trading by using the distributed ledger as examples for blockchain application in the energy sector. In an aggregation system, blockchain can perform automated transactions and settlement. In the summer of 2017, the Dutch TSO, TenneT initiated a blockchain pilot project to enable decentralised flexibility from car batteries (TenneT, 2017f). In this pilot, flexibility from car batteries is offered based on the imbalance on the high voltage grid and the availability of car batteries. In this pilot, the blockchain enables each car to participate by recording their availability and their action in response to signals from TenneT (TenneT, 2017f).

1.7 The need for a system integration approach to enable decentralised flexibility

Currently, neither aggregation systems has been implemented in the Dutch electricity system. Eid et al. (2015) mention that the aggregator role is not self-emerging. Amongst other things, DSO parties are for example not allowed to perform the role of the aggregator within the current regulatory frameworks (ACM, 2017b). Uncertainty about roles and responsibilities are an implication in establishing the role of a physical aggregator and many other complexities from a technical and institutional dimension from the perspective of both decentralised flexibility and the development of an aggregation system within the electricity sector exist.

The electricity system can be considered as a socio-technical system wherein the engineering and institutional dimensions are heavily intertwined, and which consists out of several interconnected sub-systems. Because of the intertwined character of the engineering and institutional perspective in the power sector, reforming and matching technological- and institutional elements correspondingly are crucial in designing energy systems such as an aggregation system. Verzijlbergh et al. (2014) refers to this as system integration, defined as:

“The process of jointly shaping the technical and institutional sub-systems”

From the definition of system integration by Verzijlbergh et al. (2014), it can be concluded that the alignment between technology and institutions is very important in establishing a future aggregation system. Until this day, the design of energy infrastructures remains rather fragmented (Scholten & Künneke, 2016). It is for example currently unclear what the consideration of a system integration approach means for the ability to implement both aggregation systems. Previous literature on the aggregator role for example was mainly focused on the analysis of the aggregator from a singular perspective by either focussing on aggregator market model optimisation (Biegel et al., 2014; S. Burger et al., 2016; Mahmoudi et al., 2017; Sandels et al., 2011; Sbordone et al., 2015), or the aggregator market positioning (Bessa & Matos, 2010; Carreiro et al., 2017; Dethlefs et al., 2015; Eid et al., 2016; Eid et al., 2015; Gómez San Román et al., 2011; Ikäheimo et al., 2010; Lynch et al., 2016; USEF, 2015). The only work that comes to sort of a system integration approach is the practical report of Smart Grid Task Force (2015) which makes regulatory recommendations on improving operation implications to enable adoption of the aggregator model in electricity market. Blockchain technology is only currently emerging and therefore literature only focusses on the potential of blockchain in the energy sector such as in (C. Burger et al., 2016; Lavrijssen & Carrillo, 2017; PWC, 2016a). C. Burger et al. (2016) and Lavrijssen and Carrillo (2017) briefly stipulate on regulatory barriers of adopting blockchain technology in the electricity sector. General blockchain literature mainly discusses the potential of blockchain in general market structures and organisation (Davidson et al., 2016; MacDonald et al., 2016; Swan, 2015; Tapscott & Tapscott, 2016).

1.8 Preview of research results

Performance of a potential implementation of the aggregator role and a blockchain application is heavily determined by its ability to fit within the current technical and institutional configuration of the Dutch electricity sector. Currently, it is still unclear what elements in the Dutch electricity sector challenge- or provide opportunities for the aggregator role and blockchain application by considering the system integration perspective. This research shows that the aggregator model for decentralised flexibility is at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector. The role of the aggregator as market intermediary however, fits current sector parties such as energy retailers. Central steering by the aggregator allows rules, roles and responsibilities to be assigned very specifically. Th aggregator however, implies a strong formalised relational environment causing a high degree of operation, and interaction complexity expected to induce significant transaction costs. At an coordination level, many complications in the operations and control of transactions are currently present.

The model for decentralised flexibility operated by a blockchain application shows to be both at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector as well as with the role of current parties operating in the sector. Due to disintermediation it is very hard to assign specific roles, rules and responsibilities. Organising the blockchain in a private network typology, implementation of steering- and regulating mechanisms are possible. Private blockchains however opposes the full potential of disintermediation and self-organisation. Because of the absence of full disintermediation, the question is to what extent the aggregator and blockchain actually differ in terms of organisation. In terms of coordination, blockchain is not in need for formalisation of relationships, making coordination less complex which has a positive effect on transaction costs. However, also in a blockchain application many coordination complications in the operations and control of transactions still present.

It was expected that blockchain could make the aggregator role obsolete. This research however shows that this is not the case in the specific use case of unlocking decentralised flexibility, since blockchain is not able to provide the full potential of disintermediation and self-organisation.

2 Research formulation

This chapter zooms in on the formulation of this research project. First, 2.1 elaborates on the detailed scope of the research. Subsequently, 2.2 identifies the knowledge gaps that led from chapter 1 and the review of existent literature. Next, section 2.3 mentions the problem statement of this research and 2.4 discusses the objective of this research. This all led to the definition of the (sub) research question(s) in section 2.5. The overall research relevance from a societal and scientific perspective is discussed in 2.6. The research methods and its elements are discussed in 2.7. Finally, 2.8 provides a visualisation of the thesis outline.

2.1 Scope of the research

The scope of this research is to identify challenges and implications of the system integration among two aggregation systems, the aggregator and a blockchain application, in the environment of the Dutch electricity sector. By taking system integration into consideration, an analysis is performed that simultaneously takes the engineering- and institutional perspective into account. The system integration perspective in this research is conceptualised by the comprehensive design (CD) framework because of its unique character by considering both the concepts of system integration and energy infrastructure. The framework therefore seems to be very suitable for applying in this research. In the CD framework, the engineering perspective refers to the engineering systems related to the commodity flow in the supply chain, the tangible assets involved in the operation of the electricity sector. The institutional perspective refers to the environment of economics and institutions that determine the economic performance the energy system.

The detailed design of both aggregation systems is outside the scope of this research, implying that the level of detail in the analysis of both the engineering and institutional perspective is rather highly aggregated. Specific design of artefacts relating to the aggregation systems are for example outside the scope of this research. In the institutional perspective the scope is for example on how current electricity markets challenge the implementation of the aggregation systems. Considering a blockchain aggregation system, the focus in the engineering perspective should be on the typology and configuration of the blockchain network instead of the specific coding operating the blockchain network. This research can therefore be used in order to identify the most relevant challenges and implications in implementing both aggregation systems. From the results of this research ultimately a bridge to the detailed design can be initiated.

2.2 Knowledge gaps

As discussed, there is a need for a system integration approach in analysing two possible aggregation system in deploying decentralised flexibility in the Netherlands. Crucial in system integration is the alignment between the engineering and institutional perspective. From reviewing the literature the conclusion can be made that it is still unknown how engineering- and institutional components should be aligned to enable an aggregation system to unlock decentralised flexibility. It is also yet unclear what challenges arise in achieving alignment between the technical and institutional dimension. Knowledge gaps are therefore identified as follows:

- It is unclear how the engineering perspective of the aggregator role and a blockchain application in unlocking decentralised flexibility challenges the institutional perspective and vice versa.
- It is unclear what factors in the Dutch electricity sector affect the implementation of the aggregator role and a blockchain application in unlocking decentralised flexibility.
- It is unclear what the most important design implications of the aggregator role and a blockchain application in unlocking decentralised flexibility are by incorporating the integration of institutional- and technical aspects.
- It is unclear how an integrative design, incorporating system integration, for both the aggregator role and a blockchain application in unlocking decentralised flexibility could look like.

Providing an answer to knowledge gaps above could lead to useful insights for the development of an aggregation system in the Netherlands. Due to the time constraint of this research the focus is not on the detailed design of the aggregation system, but on providing insights in challenges and implications of the system integration.

2.3 Problem statement

Considering the lack of focus on system integration and the uncertainty of challenges and implications of implementing an aggregation system in the Dutch electricity sector, the problem statement of this research is defined as follows:

Problem statement:

"It is unclear what challenges and implications arise in the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector"

2.4 Research objective

Considering that it is still unclear what challenges and implication arise by the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity and the need to identify these challenges and implications to be able to make a system integrative design, the research objective is defined as follows:

Research objective:

"To identify system integrative challenges that arise from the aggregator role and a blockchain application in offering decentralised flexibility in the Dutch electricity sector."

2.5 Research questions

Considering the knowledge gaps, problem statement of this thesis project and the research objective of this thesis project as delineated in 2.2, 2.3 and 2.4, the main research question is defined as follows:

> *Main research question:*
>
> **"What system integration challenges need to be overcome to enable the implementation of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?"**

System integration challenges and implications relate to those challenges and implications that are triggered by integrating a specific aggregation system in the environment of the Dutch electricity sector. Besides challenges and implications present within the current design environment of the Dutch electricity sector that hamper the implementation of a specific aggregation system also refer to system integration challenges. To provide a solid answer to the main question, four sub research questions have been identified.

1. How can a system integration approach be conceptualised in the analysis of energy infrastructures?
2. What are relevant characteristics of the Dutch electricity sector to be considered in the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?
3. How can the aggregator role and a blockchain application be conceptualised in the case of unlocking decentralised flexibility in the Dutch electricity sector?
4. What design implications arise from the perspective of system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?

2.6 Research relevance

This research will contribute in a societal way as well as from a scientific point of view. From a societal perspective, this research can contribute to the development of a system integrative design of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector and ultimately to the reliability and sustainability of the Dutch electricity sector. From a scientific point of view, this research will contribute to the exploration of the aggregator role and blockchain applications in the Dutch electricity sector. This provides insight to energy sector governmental bodies and to actors which have interest in implementing either one of the aggregation systems

Especially, blockchain is a concept that currently is rather unexplored in the scope of the electricity sector. This research contributes to the exploration of blockchain applications in the electricity sector. A second contribution from the scientific perspective is a test of the CD framework. The CD framework seems promising for the complex design environment of the aggregator role and a blockchain application. Yet, the framework remains untested and it is therefore uncertain whether it can provide the promising role as discussed in Scholten and Künneke (2016). By applying the principles and concepts underlying the CD framework in the analysis of this research, the research contributes to testing the added value of the CD framework. Besides, with the lessons learned from this research by applying the framework, the research can possibly contribute in further scrutinising the framework where necessary.

2.7 Research methods

This section provides an overview of the research methods used in this thesis project and discusses the application of the specific methods and the linkage to the (sub) research question(s) presented in 2.5.

2.7.1 Overview of research methods

The core research methods are obtained from applying the CD framework as the theoretical framework which will be conceptualised in detail in chapter 3. Table 2-1 provides an overview of the linkages between sub research questions, research activities and research methods.

Table 2-1: Research questions and relating research- activities and methods

Sub research question	Research activity	Research method
1. *How can a system integration approach be conceptualised in the analysis of energy infrastructures?*	• Elaborating on the need for a system integration approach considering an aggregation system • Elaborating on the CD framework and other system integration approaches	Literature study
2. *What are relevant characteristics of the Dutch electricity sector to be considered in the system integration of the aggregator role and a blockchain application in unlocking decentralized flexibility in the Dutch electricity sector*	• Describing the Dutch electricity sector from an integrative perspective by using the CD framework	Literature study
3. *How can the aggregator role and a blockchain application be conceptualised in the case of unlocking decentralised flexibility in the Dutch electricity sector*	• Describing the concepts of a physical aggregator and blockchain applications • Conceptualise the functioning of the aggregator role and a blockchain application in aggregating distributed flexibility	Literature study
4. *What design implications arise from the perspective of system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?*	• Analysing the integrative fit of the aggregator and a blockchain application within the Dutch electricity sector • Identify design implications • Validate, nuance and complement found insights	Expert interviewing

2.7.2 Elaborating on research methods

This section elaborates on the elements of the presented research methods in 2.7.1. Within this section, the most important characteristics, application, drawbacks and limitations of the specific research method by using it in this research will be discussed.

Literature study

Literature study, a specific category of desk research (Verschuren et al., 2010), is performed in this thesis during the execution of the first three sub research question. The main characteristic of a literature study is that it makes use of existent material in books, journal papers, practical reports, and so forth (Verschuren et al., 2010).

In the first research question, literature study is used to elaborate on the concepts, system integration and socio-technical systems. This part is mainly used to discuss the concepts and the application of the CD framework. In the second research question, literature study is used to elaborate on the Dutch electricity sector as design environment from the integrative perspective. These insights are used to enable the elaboration on the fit of aggregation system within the electricity sector later on. In describing the Dutch electricity sector as design environment, the physical and the institutional layer of the Dutch electricity sectors are analysed thoroughly guided by the principles of the CD framework. This will include describing the technical system, its components, critical functions and constraining factors for the physical layer and electricity markets, relevant stakeholders and relevant rules- and regulations for the institutional layer. Finally, the third research question, literature study is used to elaborate on the concepts of the aggregator role and a blockchain application to be able to situate them in the Dutch electricity market. Besides current literature, the USEF framework is used to conceptualise the aggregator role and a blockchain application.

The concepts of the aggregator and blockchain application in providing decentralised flexibility are relatively new, and mainly conceptual. No large scale applications of the aggregator role nor blockchain in providing distributed flexibility are present. A limitation is that specific information on both the aggregator and blockchain in providing distributed flexibility is limitedly available. Especially blockchain is a concept very little researched on in the application of energy infrastructures.

Expert interviewing

Expert interviewing is a qualitative empirical research method in order to obtain relevant information from experts (Bogner et al., 2009). As seen in the research flow diagram in 2.8, the expert interviews serve as an iteration step in the analysis of factors that hamper the system integration of the aggregator role and a blockchain application. The initial analysis is discussed with experts to validate the analysis and complement where necessary. The gained insights from the interviews form a substantive input for this analysis and are therefore processed in the regular storyline. A difficulty of expert interviewing is to select the most relevant stakeholders relating to the specific subject to obtain the most relevant and trustworthy information. For more details on the interviewee selection and results of the interviews, consult appendix 0.

2.8 Research flow diagram

Considering the research (sub-) question(s), research activities and research methods, this section visualizes the outline of this research (see Figure 2-1). The small boxes on the left hand side represent a specific section, whereas the smaller boxes in the middle boxes represent research activities within a specific section. Where applicable, the relating sub-question defined in section 2.5 have been linked to a specific sub-section. As seen in the research flow diagram on the next page, arrows indicate interlinkages and relations between the several research-elements and activities. The most important interlinkages and relations will be discussed below. The concepts of the CD framework as discussed in chapter 3 serves as an input both the demarcation of the electricity sector. The concepts of the CD frameworks are also used in the identification of design implication together with the output from describing the electricity sector and conceptualising the aggregator role and blockchain application. The identified design implications are subsequently iterated by means of expert interviews and classified on relevance to form the bridge to design. Finally, the research results are discussed based on the results from the analysis and previous chapters.

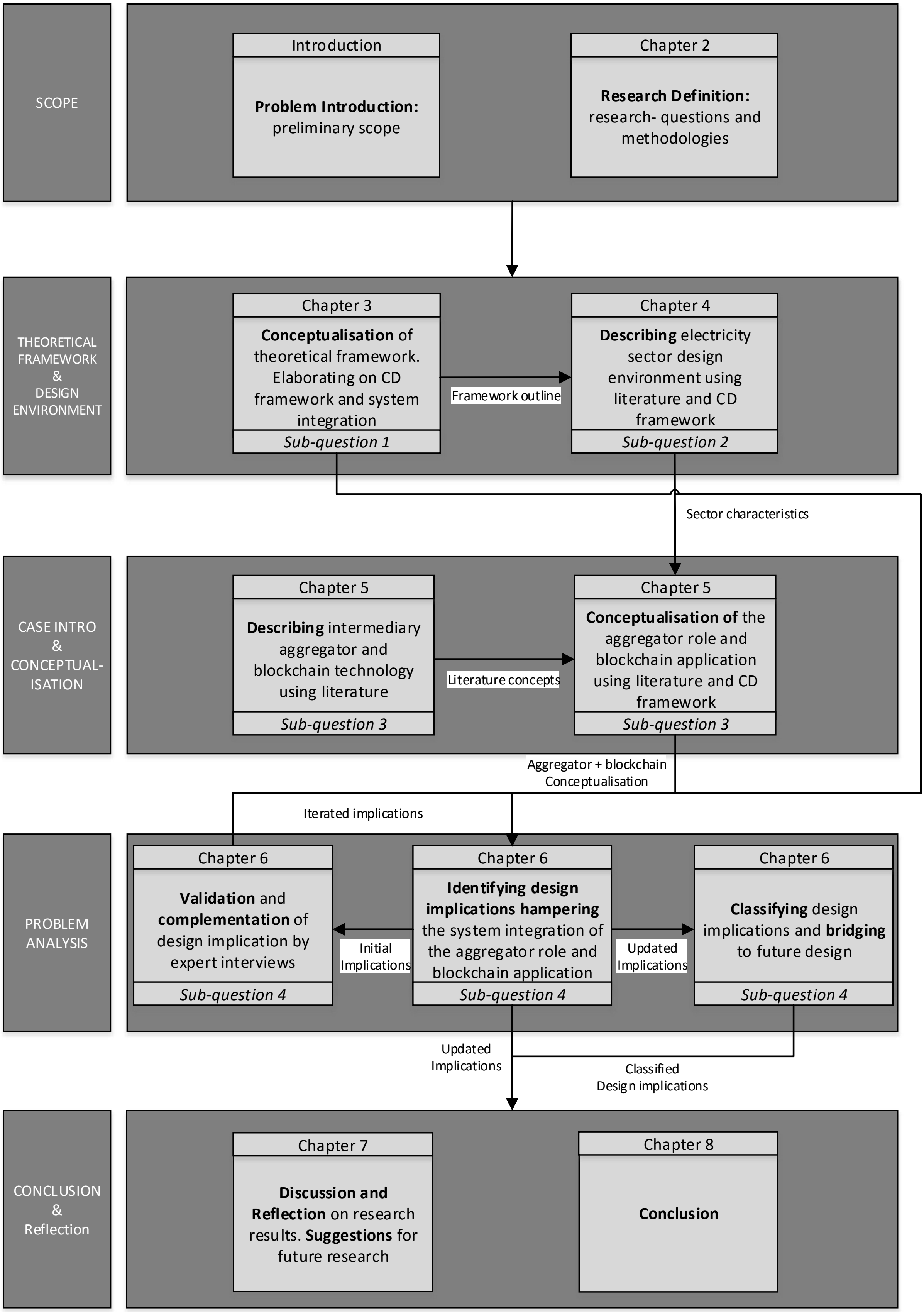

Figure 2-1: research flow diagram

3 Conceptualisation of system integration within energy infrastructures

This chapter elaborates on the sub-research question relating to the conceptualisation of energy infrastructures: *How can a system integration approach be conceptualised in the analysis of energy infrastructures?* As elaborated in this chapter, the comprehensive design (CD) framework is the guiding theoretical framework that serves as the conceptualisation of an energy infrastructure in this research. The rationale of considering the electricity sector as a socio-technical system is discussed in 3.1. Next, 3.2 discusses the need for a design framework that incorporates both the engineering and institutional perspective. Section 3.3 and 3.4 discuss the outline of the CD framework in more detail by elaborating on the conceptualisation of the engineering- and economic layers and discussing the specifics of the CD framework respectively. Section 3.5 discusses the limitations of the CD framework for this research. Finally, 3.6 bridges the results and conclusions from this chapter to the remainder of the research. For a more detailed description on the underlying concepts and theories of the CD framework, one can consult the original work of Scholten and Künneke (2016).

3.1 Socio-technical systems literature review

The CD framework is built upon the concept of socio-technical systems. Several definitions and notions on socio-technical systems are found in literature. According to Weijnen and Bouwmans (2006), socio-technical systems are characterised by the interaction between physical- and actor networks and behaviour of energy infrastructures as a socio-technical system can only be fully understood by analysing the integrated system rather than the behaviour of the physical- or social network. Due to the increasing variety and complexity in actors in networks, there is an increasing need for a socio-technical approach in designing and analysing systems. In the past, the physical network dominated decision-making, whereas in today's decision-making the economic system has become more dominant (Weijnen & Bouwmans, 2006). De Bruijn & Herder (2009) refer to socio-technical systems as systems were both physical-technical elements and networks of interdependent actors are involved. They state that full integration of both perspectives is essential but more or less impossible. Because of the intertwined character of socio-technical systems, they argue that these systems should be analysed and designed by designers who are able to switch perspective and apply both perspectives in a useful way (de Bruijn & Herder, 2009). The notion on system integration by Verzijlbergh et al. (2014), as introduced earlier, was based on considering energy infrastructures as a socio-technical system.

Scholten and Künneke (2016) perceive energy infrastructures as complex adaptive socio-technical systems. Within this theory, infrastructures are structured around a technical core and are embedded in, sustained by, and interact with, comprehensive socio-historical contexts (Ewertsson & Ingelstam, 2004). In evaluating, analysing, and designing energy infrastructures the focus should therefore not purely be on the technical infrastructure. Scholten and Künneke (2016) state that the focus in energy infrastructures should be more on "*how technologies, actors and rules mutually influence and continuously reconstitute each other in a co-evolving manner characterised by lock-in and path dependency (p. 3)*". Considering this, performance of energy infrastructure is based on the interaction between techno-operational characteristics, energy market dynamics, and institutional arrangements.

3.2 Fragmented design in socio-technical energy infrastructures

Despite of the acknowledgement of the existence of interaction between technology and institutions in socio-technical energy infrastructures, the design of energy infrastructures is rather fragmented (Scholten & Künneke, 2016). Dominant perspectives in designing the technical systems and economic systems are system design and market design respectively. System design mainly focusses on decomposing and analysing technical systems and sub-systems from an engineering perspective. System design is a design method built upon the concepts of logical design steps such as defined in Dym et al. (2014), Herder and Stikkelman (2004) and Sage and Armstrong (2000). Important components in system design are mapping functional requirements, objectives and constraints, the design space, models and modelling (de Bruijn & Herder, 2009; Herder et al., 2008). Market design focusses on analysing the working principle and requirements of markets in order to fix them when necessary or build them bottom-up when missing (Roth, 2007).

Approaching design by a singular perspective is troublesome in many ways. Since energy infrastructures are characterised by their heavily intertwined environment of technology and institutions, complexity is ignored by adopting a singular perspective. Besides, using a singular design perspective for engineering and economic design may generate conflicting requirements. Furthermore, it's unclear to what extent designs from one perspective influences the opposite perspective (Scholten & Künneke, 2016). When designing an aggregation system from a purely technical perspective will lead to other design options than also considering an operational system which should fit into an institutional environment. Scholten and Künneke (2016) proposed the comprehensive design (CD) framework. The CD framework is chosen in this research because of its promising feature of conceptualising the system integration perspective in an energy infrastructure environment. Other literature discussing system integrative approaches (Herder et al., 2008; Hermans et al., 2006; Janssen et al., 2007; Mayer et al., 2005) provide a way less conceptualised integrative approach, and focus on different sectors. By using the system integrative approach as elaborated on in the CD framework, concepts of a system integrative approach in energy infrastructures as well as the concepts of the aggregator role and a blockchain application unlocking decentralised flexibility are addressed in this research.

3.3 Structuring the design variables of systems design and market design

The CD framework is built upon the concept of socio-technical systems and the principles found in system- and market design. In establishing a comprehensive framework, the design variables of both perspectives are structured in a similar manner by reconfiguring the four layer model of institutions by Williamson (1998), a keystone of the new institutional economics (NIE). The engineering – and economic perspective are aligned among a revised version of the four layer as defined by Williamson. Doing this "*reconfigures existing insights, sorting the design variables, and makes them comparable between the systemic and market dimension… The core idea is that the same layers in both dimension revolve around similar concepts and/or design knobs: access, responsibility and coordination (Scholten & Künneke, 2016)*(p.9).

3.3.1 Structuring the engineering perspective

The engineering perspective is reflected by the commodity flow of an energy infrastructure, the tangible assets involved in the operations of the electricity sector. Figure 3-1 provides an overview of the engineering perspective in energy infrastructures inspired by the four-layer model of Williamson (1998) as conceptualised in the CD framework. The dynamics in this conceptualisation is presented by the fact that the most upper layer constrains the consecutive layers. Big inadequacies in design lead to a feedback relation from lower layers to the upper ones (Scholten & Künneke, 2016).

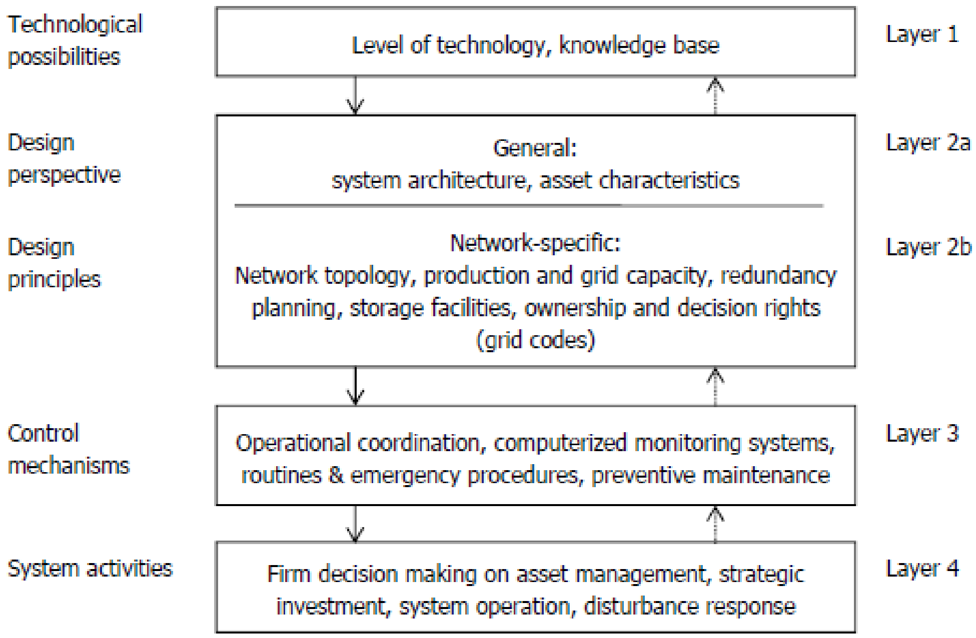

Figure 3-1: The engineering perspective, four layers of conceptualisation (Scholten & Künneke, 2016)

The first, and most upper layer refers to the level of technology and knowledge on technology present in society. Since this layer is tend to change only very slow, influencing this layer by design is very hard. Relating to the electricity sector, changes in this layer occurred with the introduction of innovative technologies such as smart grid concepts, automation and emerging renewable technologies (Scholten & Künneke, 2016).

The second layer, refers to the infrastructural design within energy infrastructures. Design choices within this layer concern the system architecture and asset characteristics. One should consider how the infrastructure should ensure system robustness and plan for eventualities by physical infrastructure design choices such as network topology, production, and storage capacity. Also relevant in this layer is the assignment of specific roles and responsibilities relevant for the physical assets, such as the planning, development, operations, maintenance and coordination (Scholten & Künneke, 2016).

The third layer, refers to the control mechanisms that enable reliable operation of coordination, services and/or information. This layer includes computerized monitoring systems, routines and emergency procedures, preventive maintenance, switching stations, such as SCADA systems and energy management systems (Scholten & Künneke, 2016).

The fourth layer, the system activities refer to firm decision making, concerning daily flow activities ensuring reliability. This mainly refers to how individual firms decide upon asset management, strategic investments, system operation and disturbance response. At the end, all system activities performed by individual actors in the systems make up the system performance within the energy infrastructure.

3.3.2 Structuring the economic perspective

Figure 3-2, provides an overview on how the economic perspective can be conceptualised by applying the four layer model of institutions as defined by Williamson (1998). In analysing the institutional environment, four levels of analysis are important; informal institutions, formal institutions and governance, organisation and market activities (Scholten & Künneke, 2016).

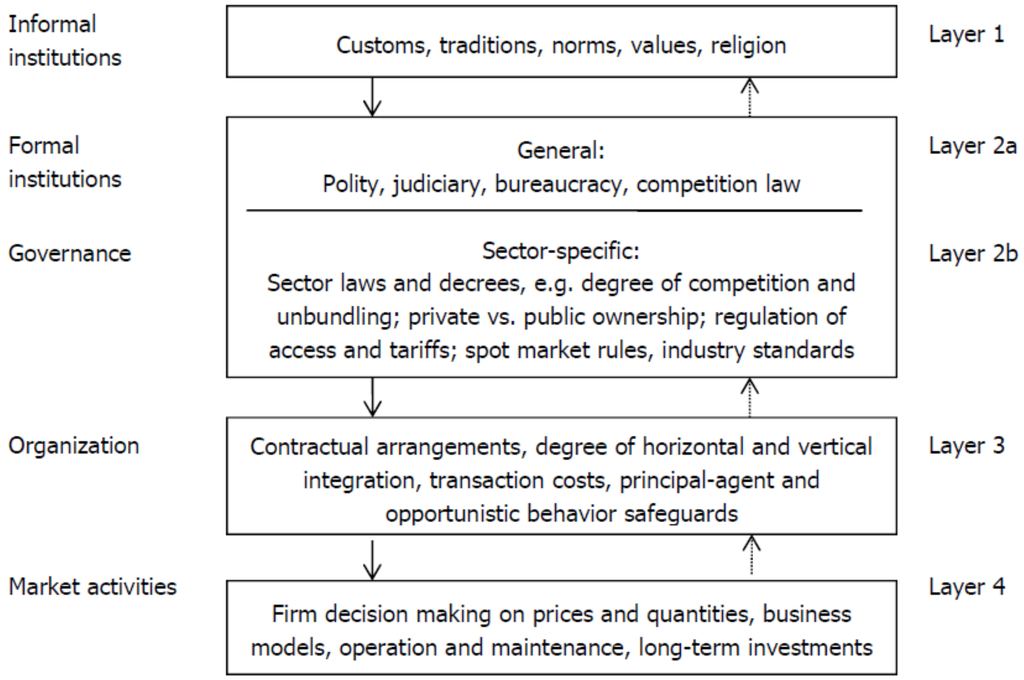

Figure 3-2: The institutional perspective, four layers of conceptualisation (Scholten & Künneke, 2016)

The first layer refers to informal institutions such as traditions, customs, norms and values in a specific society. Informal institutions emerge over a large span of time and are not subject to fast changes. Informal institutions are therefore considered as a given variable which is not subject to design and which influences formal institutions of an energy infrastructure (Scholten & Künneke, 2016).

The second layer refers to formal institutions such as laws and regulations. In the most general way, this layer refers to *"how the political-bureaucratic system works, how state-society relations are framed and how the rule of law is exercised"* (Scholten & Künneke, 2016). From an economic perspective, the governance of the energy markets and the energy sector are the relevant concepts, meaning that formal institutions should focus on how individual actors should be incentivised in such a way that the most optimal economic performance is achieved. Core design issues in this layer are competition, ownership and regulation (Scholten & Künneke, 2016).

The third layer refers to economic organisation, the play of the game. Focus in this layer is on which organisation could accommodate and coordinate transactions in the market, given the formal institutions in layer 2. The question is what type of markets, contracts, organisation structure or market regulation should coordinate a specific transaction (Scholten & Künneke, 2016).

The fourth layer focusses on short term market activities such as company decision making on prices and quantities, business models, optimisation of operation and maintenance and long-term investments. Just as in the engineering four layer model, the total of activities in defined layers results in market outcomes and performances which are expressed in terms of availability, affordability, acceptability and sustainability. (Scholten & Künneke, 2016)

3.4 Towards a framework for comprehensive design- variables of alignment

Layers in both the engineering and economic perspective are aligned among the design knobs of access, responsibility and coordination. Alignment should be pursued within a specific perspective but also between the different perspective. Access defines the alignment between the upper layers and layer 2a of both layers from engineering and economic perspective (see Figure 3-1 and Figure 3-2, the systemic and institutional environment. Responsibilities define the alignment between both perspective on layer 2b, the design principles and the governance. Coordination is about the alignment between the third layer of both perspectives, control mechanisms and the organisation.

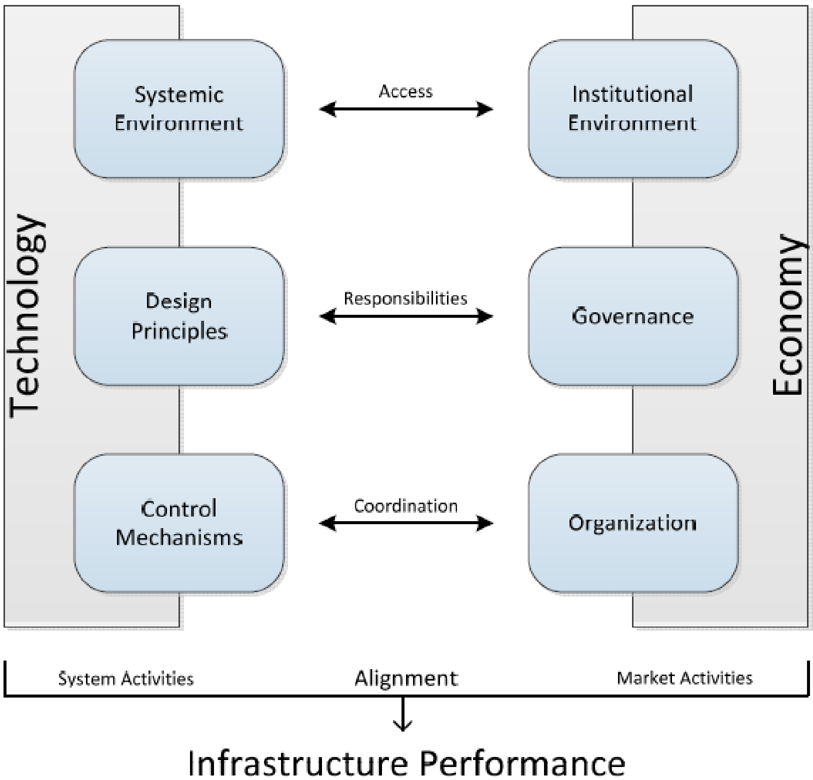

Figure 3-3: The alignment between the technical and institutional perspective (Scholten & Künneke, 2016)

3.4.1 Alignment in access

Access refers to the alignment of the systemic and institutional environment, the high level design of infrastructures. As elaborated in 3.3, in the technical dimension this refers to the system architecture and assets characteristics and in the economic dimension this refers to the formal institutions. Two types of access, open- and closed access, have been distinguished in the CD framework. In the technical dimension this basically refers to accessing a specific infrastructure. Open access in infrastructures for example, is characterised by access to all actors or organisations willing to participate and perform activities in a specific infrastructure. Closed access on the other hand only allows for specific assigned actors or organisations to perform activities in a specific infrastructure. In the economic dimension, access refers to the accessibility to infrastructure markets. Open access refers to classic competitive markets that are open to potential entrants, where closed access refers to strict regulated markets. Alignment is established when having corresponding forms of access in both perspectives. If a specific part of an energy infrastructure is openly accessible to multiple actors and organisations, the institutional environment should be organised in an open way as well (Scholten & Künneke, 2016). Relating to both aggregation systems, the alignment of access should discuss state of the technology of both systems and how the technology can fit in with the current informal institutions on the higher level and how choices for general design perspectives can be embedded within the current formal institutions.

3.4.2 Alignment in responsibilities

Responsibilities refer to the alignment in more detailed specific design of infrastructures. Important in this design knob is the relation between technical design principles and market governance arrangements. In the technical dimension, design should focus on describing responsibilities on the management of technical artefacts as defined in the commodity flow in a specific energy infrastructure. The economic dimension refers to the more specific assignment of ownership and decision rights considering decisions in upper layers. This should be done in such a way to avoid market imperfections and opportunistic behaviour, to strive for the most effective and efficient infrastructure operation. In aligning responsibilities, one should ensure that responsibilities in both dimensions do not contradict (Scholten & Künneke, 2016). Relating to the aggregation systems it is important to evaluate what parties are technically responsible and whether this can be aligned with responsibilities from the economic point of view.

3.4.3 Alignment in coordination

Coordination relates to the alignment of the control mechanisms in the technical dimension and the organisation in the economic dimension. Coordination is about the interaction between different actors in the performance of techno-operational coordination and relating market transactions. In the technical dimension, coordination refers to how the interaction among actors involved in operational activity is managed. Questions that are relevant, are the level of management (e.g. centralised or decentralised) and degree of automation. In the economic dimension, coordination refers to how transactions between a variety of actors under given property rights, market structures and regulation is managed. Who should be assigned with what rights, what market structure is relevant and what are the best modes of organisation? Ultimately, the chosen mechanism of coordination in both dimension should be complement with each other and not contradictory. Relating to the two aggregation systems, there should be analysed what type of organisation aligns with the type of techno-operational activity opted by a specific aggregation system. (Scholten & Künneke, 2016)

3.5 Limitations of using the CD framework

The CD framework proposes a conceptualisation of a system integrative approach in energy infrastructures. Scholten and Künneke (2016) elaborate on some limitations and possible future improvements of the CD framework. The main limitation of the CD framework is the fact that it is untested until this day and therefore not operationalised and scrutinised in a sufficient way. Proposed improvements are to elaborate on the degree of needed alignment between the different dimensions, to determine how one could move from one dimension to another, how to include a more ICT based way of operation, move towards a more dynamic representation of system- and market design and to include the role of actors in the alignment of both dimensions.

Another limitation of the CD framework is that it focusses on general energy infrastructures. This is somewhat troublesome in the conceptualisation of the upper layers of the CD framework which elaborates on level of knowledge on technology, broad state society and informal institutions in its broadest form. In designing a general energy sector these variables are of relevance. However, this research focusses on the analysis of a specific sub-system within the electricity sector. An argument can be made that the aggregation systems are embedded within the level of knowledge of technology, informal- and formal institutions of the electricity sector and that the broader state formal institutions can be disregarded.

Considering the fact that the CD framework is currently untested and it not operationalised and scrutinised in a sufficient way (e.g. no specific guideline on how to apply the CD framework is available), it is not completely certain whether applying the CD framework can provide useful outcomes. The value for the framework in providing a comprehensive overview of an energy infrastructure and identifying implications and challenges by integrating a new technology is looking promising though. By being the theoretical framework of this research, the CD framework is subject to its first test. This research therefore might provide insights in the further operationalisation and scrutinizing of the framework.

3.6 Concluding remarks and using the CD framework in this research

The research question opted to answer in this chapter is: *How can a system integration approach be conceptualised in the analysis of energy infrastructures?* This research question was drafted to gain insight in a system integration conceptualisation and how this can be used within the scope of this research. Within this research, the conceptualisation of the energy infrastructure is represented by the CD framework, providing a structured overview for analysis with the alignment layers of access, responsibilities and coordination. System integration can be achieved when alignment is ensured in the design layers of access, responsibilities and coordination within- and between the engineering- and economic perspective. In this research, the CD framework can be used to identify on what level challenges arise relating to the system integration of both aggregation systems. By analysing the concepts of the aggregation systems in a structured manner along the layers of access, responsibilities and coordination, a comprehensive overview of design implications across can be drafted. Insights as gained in this chapter therefore serve as input in structuring the concepts of the electricity sector design environment in chapter 4, and the detailed analysis of challenging factors and design implications of the aggregator role and the blockchain application in chapter 6.

4 Design environment – The Dutch electricity sector

In this chapter an answer is provided to the second sub-research question, *What are relevant characteristics of the Dutch electricity sector to be considered in the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?* An answer is provided by describing the main elements of the electricity sector supply chain along the CD framework design layers of access, responsibilities and coordination. The sector is analysed in its entirety since access, responsibilities and coordination across the entire sector might need to be reviewed for the system integration an aggregation system. Think for example about revising roles and responsibilities of current market parties regarding balancing the electricity grid, or operating congestion management, the coordination in different electricity markets, and adjusting current regulatory frameworks. Due to the decentralised perspective of the flexibility models, the connection with international market is discarded

In this chapter, 4.1 discusses major developments in the electricity sector evolved over the last decades. Chapter 4.2 discusses the current systemic- and institutional environment of the Dutch electricity sector along the access design knob. Chapter 4.3 discusses the technical design principles and market governance of the Dutch electricity sector and how they are both aligned along the responsibility design knob. Chapter 4.4 elaborates on several control mechanisms and the organisation of interaction in the electricity sector and how these concepts are structured along the coordination design knob. Finally, 4.5 discusses the lessons learned in this chapter.

4.1 The Dutch electricity sector- a changing environment

As discussed by Scholten and Künneke (2016), energy infrastructures are characterised by the concepts of co-evolution and path dependency. Examples of this are the market reforms initiated by both the European Union and the Dutch government. With the introduction of the Electricity Directive 96/92/EC, liberalisation of the electricity sector was initiated within Europe (de Vries et al., 2010). Liberalisation required the electricity sector to undergo major changes and played a big role in the current configuration of the Dutch (and other European) electricity sector(s). Three major acts played are of importance; the Energy Act of 1989, the Electricity Act of 1998 (which was based on the European Electricity Directive 96/92/EC) and the Third Energy Package. Since the requirements of the 2003/54/EC Directive were already implemented by the Electricity Act of 1998, the 2003/54/EC Directive is not discussed in this section.

The Energy Act of 1989

Until 1989, the Dutch electricity sector was organised by vertically integrated local monopolies, with only four generation companies, and coordination and planning in hands of the Ministry and the SEP, the Association of Electricity producers. Regulation restricted other parties from entering the market. Competition was introduced with the Energy Act of 1989 in two ways. First, distribution companies, as well as large consumers, had the opportunity to choose their preferred central production company. Second, industrial players were allowed to generate and feed in decentral produced electricity, which awarded with a feed-in tariff (van Damme, 2005).

The Electricity Act of 1998

The goal of the Electricity Act of 1998 was to increase competition by introducing freedom of choice for the consumer with the introduction of liberalisation in the retail market. In extension to this act, the Dutch government also initiated legal unbundling of electricity companies, and regulated third party access to electricity networks. With this act, the electricity sector shifted from a generation oriented system towards a more demand oriented system. Another feature enabled by this act was the freedom of choice for large consumers in choosing their supplier. Soon, medium- and small sized consumers were allowed to choose their supplier as well. Another important change was that the introduction of the privatization of generation companies. Network activities were still considered as a monopoly and therefore unbundled from the competitive activities. To supervise the sector, and check for compliance with new regulation, the DTe (the precursor of the current regulator ACM) was assigned as regulator for the energy sector. (van Damme, 2005)

Third Energy Package of 2009

Finally, the Third Energy Package, was initiated to improve the functioning of the energy market. It covered the unbundling of energy suppliers from network operators, enforcing the independence of regulator, initiation of energy regulator cooperation, cross-border TSO cooperation, and the transparency in retail markets (European Commission, 2017c).

The influence of informal, and formal institutions on the energy sector as described in the CD framework are easy to be observed in changes above. With the introduction of the Energy Act of 1989 and the changing systemic- and institutional environment, new defined responsibilities and new defined ways of coordination are observed. For example, the SEP was given the responsibility to plan the central production capacity and acted as a clearinghouse between generation and supply. In the Electricity act of 1998, a new actor (DTe) was assigned with the responsibility to safeguard the electricity sector on compliance with introduced changes in the institutional environment. A final example is that the liberalisation in the retail market introduced in 1998, required new market mechanisms. Therefore, the EPEX Netherlands (the former APX) was established to enable electricity wholesale markets (EPEX Netherlands, 2017). It is therefore important to be acquainted with the influence of the systemic- and institutional environment in analysing and designing a future aggregation system.

4.2 Access: systemic- and institutional environment in the Dutch electricity sector

In the systemic environment, a trend towards sustainability enabling technologies such as smart grid concepts, energy storage technologies and improvements in renewable technologies can be observed. In the institutional environment, norms and values of society towards electricity production and the need for more sustainability in the institutional environment is observed. Access to technology and institutions is mainly open in those activities that are considered to be competitive whereas access is closed in those activities that involve a form of natural monopoly.

Production

An important characteristic of electricity production is that it is considered as a competitive privatised activity in the Netherlands with open access. Types of production can be classified along two variables, level of generation scale (large- or small scale) and type of resource (conventional or renewable). Currently, the production portfolio in the Netherlands is still dominated by large scale conventional resources (CBS, 2015). However, a shift is notable towards the use of more renewable sources and decentralised electricity production (DNV GL, 2016). In the institutional environment, production of electricity is perceived as an activity which is competitive. Considering access, both the systemic- and institutional environment are openly accessible.

Trade
Trade in electricity is essentially open to a variety of actors. However, the activity of trade is performed on a standardised power exchange and is subject to specific rules depending on the specifics of a particular market (de Vries et al., 2010). Relating to access, the market of trade is open to players willing to participate, but institutionally restricted to rules which are determined by European regulation. European rules are directly translated into energy codes regarding to tariffs, rights and responsibilities for network users (ACM, 2017a).

Transmission
The transmission network is characterised by electricity transport of 110 kV and higher (TenneT, 2017b). The transmission network connects the large generation facilities with the transmission substations and distribution network where electricity is transported on lower voltages. In the Netherlands, as in other countries, transmission is considered as a natural monopoly. Due to this characteristic, the infrastructure assets within the transmission activity is closed and only accessible by the TSO, TenneT. This is also reflected in the institutional environment by strict regulation on transmission operations (TenneT, 2017d). TenneT, is organised according to the ownership unbundling OU model (ACM, 2013). Due to the requirement of full unbundling, TenneT is not allowed to perform any market distortive activities or operations.

Distribution and metering
The distribution network facilitates local energy transport from the transmission network to the final consumer. As transmission networks, distribution networks are also considered as natural monopolies. Access to this infrastructure is therefore regulated. In the Netherlands, the distribution network is operated by several DSOs which are assigned with a specific geographical area. Just like the transmission network, the distribution network is strictly regulated by the ACM (Netbeheer Nederland, 2017a). The metering of electricity usage is a public activity which is also carried out by the DSOs. Assets of the metering activity are the (smart) meters which generate data on consumer electricity usage. Since metering is a public activity, tariffs are regulated accordingly by the ACM (ACM, 2017c). Like TenneT, Dutch DSOs should be completely unbundled and are not allowed to perform any market distorting activities or operations (Netbeheer Nederland, 2017b).

Retail and consumption
Retail facilitates the sale of electricity as consumed by the final small consumers. In order to facilitate final retail consumption, every consumer is connected by a DSO with the distribution network. Retail itself is considered as a competitive activity and therefore characterised by its open infrastructure and market access. Despite the open access of the retail, one has to comply with the energy license as defined by the ACM (ACM, 2017e).

The detailed analysis on the current systemic- and institutional environment led to the schematic overview in Figure 4-1.

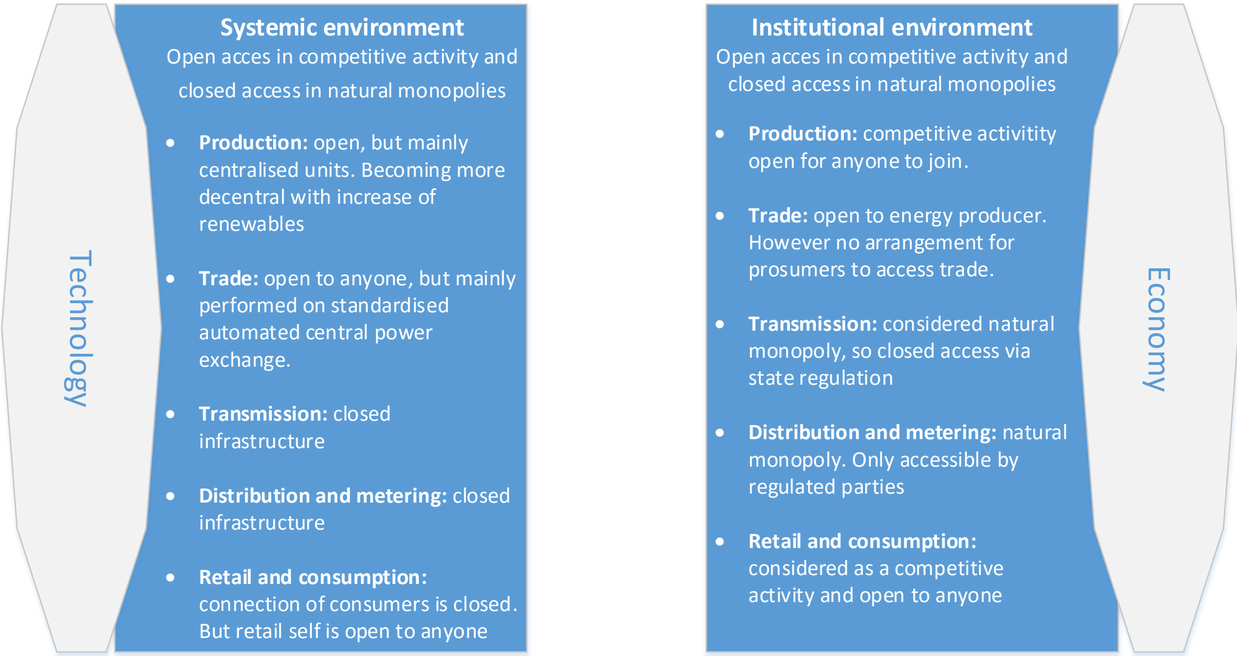

Figure 4-1: Schematic overview of systemic- and institutional environment

4.3 Responsibilities: technical design principles and economical governance

The alignment in this layer basically evaluates how, considering the systemic- and institutional environment, the control of technical operations align with the ownership and decision rights in market transactions that are assigned to a specific actor. As the analysis shows, there is a clear distribution of responsibilities in performing operations and decisions on assets in the technical perspective. In the economical perspective there is a clear ownership and assignment of decision rights, but where necessary regulations are implemented.

Production

Production is a privatised activity and actors are therefore free to generate electricity and enter the market (van Damme, 2005). Electricity is a product which can't be stored on a large scale. It's therefore desirable to accurately match the supply and demand of electricity throughout time to ensure balance on the transmission- and distribution networks. This is achieved by the assignment of balancing responsibilities. Balancing responsible parties (BRP) submit a so called energy program which indicate their planning of production and/or consumption of the BRP itself and/or its customers (de Vries et al., 2010). In this way, TenneT can ensure compliance in production and consumption of electricity over time.

Trade

Trade of electricity in the Netherlands is a competitive activity facilitated on a sport market owned by EPEX Netherlands. In this market, distributors, producers, traders, brokers, and industrial end users can trade on either a day-ahead auction or the intraday market. It differs from commodity spot markets, since prices in the day-ahead auction are determined hourly based on the accumulated supply and demand of electricity (EPEX Netherlands, 2017). The EPEX is responsible for facilitating the wholesale market of electricity. Suppliers and consumers of wholesale electricity are responsible for submitting daily bids. Besides the spot market, one can also trade electricity in bilateral agreements (de Vries et al., 2010).

Transmission
In the Netherlands, the transmission network is operated and maintained by TenneT. As defined in the Elektriciteitswet (Electricity law), TenneT is responsible for transport- and system services (and relating investments) on the transmission network and facilitating the electricity market. Besides, they are responsible for the connection with other networks (distribution and other countries) and large production facilities (ACM, 2017d). One important task of TenneT is to actively balance the supply and demand of electricity to guarantee the reliability of the electricity grid (TenneT, 2017c). As transmission is considered a natural monopoly, the activity is regulated by the ACM. The ACM decides upon the tariffs that may be charged for providing transmission services. So-called energy codes, define specific rules and responsibilities for network operators and electricity suppliers concerning tariff structures and technical codes relating to network characteristics (ACM, 2017f)

Distribution
The distribution network is operated by several DSOs which are assigned to a specific geographical area. DSOs are responsible for the infrastructural assets of the distribution networks. The major difference between distribution networks and transmission networks, is the passive character of the distribution network compared to the active management in the transmission network. The DSO is dependent on the TSO in the transmission network in energy delivery, frequency control, voltage regulation and balancing supply and demand in the distribution network (Schavemaker & van der Sluis, 2008). Regulation characteristics of the DSOs in the Netherlands are similar as for TenneT. Energy codes are also applicable to DSOs, as the regulation of tariffs is organised in a similar fashion and regulatory goals are similar.

Metering
Metering activities are the responsibility of the DSOs (Stedin, 2017b). Energy meters enable the reporting of energy usage of the final consumer. The traditional energy meter is currently being replaced with the smart meter, providing more real-time insights. Since metering is an activity performed by the DSO, the tariff for metering is regulated by the ACM (only for the metering activities concerning small consumers) (ACM, 2017c). The costs of distribution at the end, are allocated to the final consumer by the energy supplier (Stedin, 2017b).

Retail and consumption
The supply of electricity, is a competitive market. Consumers are free to choose their own supplier. Despite the competitive character in electricity supply, the market is heavily dominated by the three biggest electricity suppliers Eneco, Essent, and Nuon which approximately own 80% of the total market share (ACM, 2014). Electricity suppliers buy electricity from generation firms on the energy markets and sell it to small industries and consumers which are connected to the electricity network via a connection managed by the DSO. Retail companies are subject to certain rules for energy supply, translated into an energy license. This energy license limits the degree of freedom of retail companies in order to safeguard energy consumers. Retailers have the obligation to submit an energy program and have the responsibility of a BRP. Retailers also bear the responsibility to act as the balancing responsible entity for smaller consumers since it is technically and institutionally very complex for prosumers to execute this responsibility themselves (de Vries et al., 2010).

Schematic overview
For a schematic overview, summarising the relevant concepts of this section once can consult Figure 4-2.

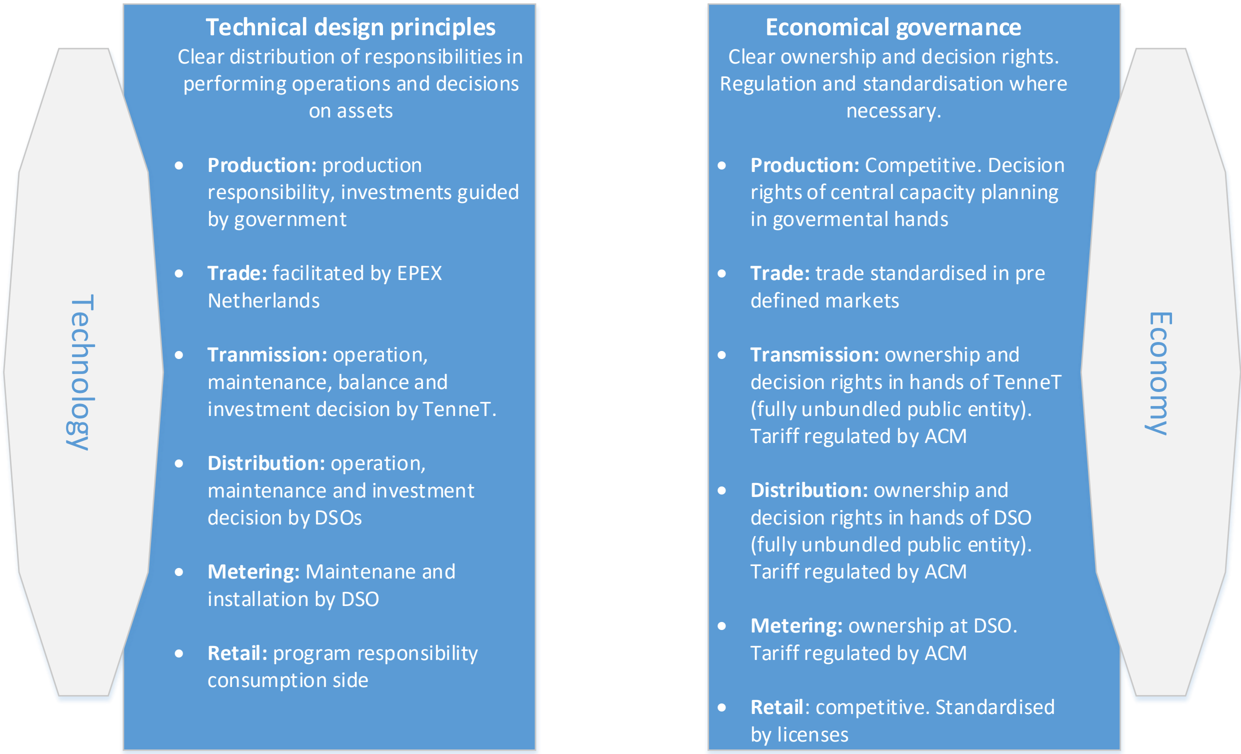

Figure 4-2: Schematic overview of technical design principles and economic market governance

4.4 Coordination: techno-operational coordination and market transactions

The coordination design knob refers to the interaction between actors in techno-operational coordination and market transactions in realising a good or service. The technical dimension of coordination refers to the way transactions in operational activities are established. From the economic dimension, coordination refers to the mode of organisation of interactions (Scholten & Künneke, 2016). As analysed in this section, control mechanisms and organisation of activities in the electricity sector are mainly organised in central mechanisms.

Coordination of electricity- trade, production and consumption

Since electricity can't be stored on a large scale, production of electricity is planned very accurately. Decisions on the planning of electricity production are made based on the planned demand of the following day which are submitted by responsible BRPs to TenneT and the EPEX. Trade and consumption of electricity therefore closely relate to the coordination of electricity production. Actors involved in this coordination are TenneT, balancing responsible parties form both the supply side and the demand side and EPEX as a trading house. The concepts of techno-operational coordination and market transactions regarding the coordination of electricity- production and trade have been presented in Figure 4-3: Overview of technical coordination and market transactions in the activity of electricity- production and trade Balancing responsible parties, electricity producers and large consumers, establish contractual agreements on how much electricity they sell and buy on the EPEX spot market (TenneT, 2017a). As long as the BRPs exactly match their e-programme, the electricity grid is in balance. BRPs can use the intra-day market to correct for expected deviations with their individual e-programme. In practice, e-programmes often differ from the actual production and consumption of BRPs. Differences can lead to imbalances on the electricity networks which is solved by

TenneT. The coordination of the operation of balancing the electricity grid is discussed in the next section. The transactions and the coordination relating to electricity- trade, production and consumption have been summarised in Table 4-1.

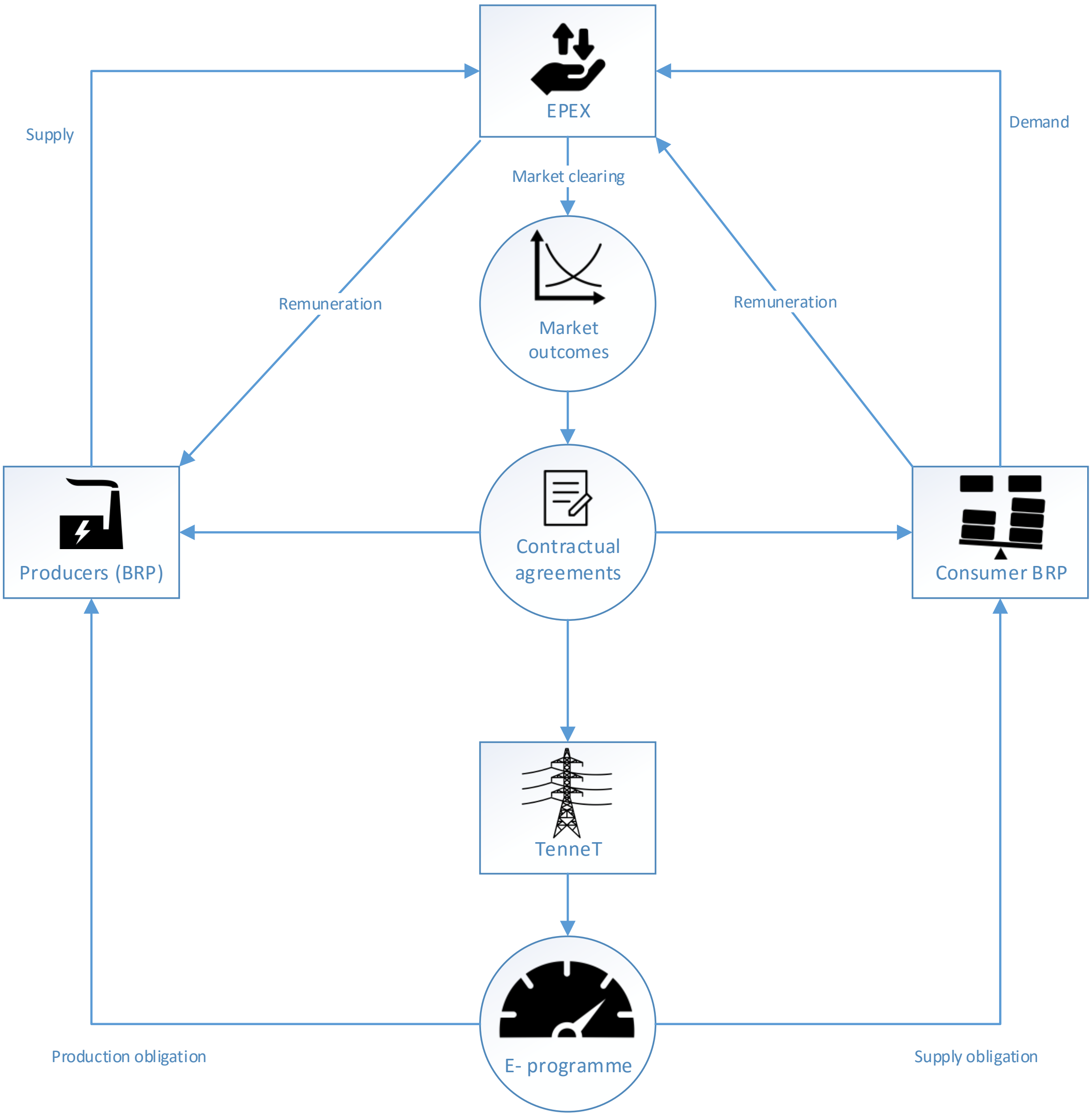

Figure 4-3: Overview of technical coordination and market transactions in the activity of electricity- production and trade

Table 4-1: Overview of the coordination of electricity- trade, production and consumption

Transaction	**Technical coordination**	**Organisation of interaction**
Trade – wholesale	Centralised Digital	Spot markets Contractual agreements
Trade – bilateral	Decentralised Negotiation	(Long-term) contracts
Production	Centralised Digital	Spot markets Contractual agreements E-programme
Consumption	Centralised Digital	Spot markets Contractual agreements E-programme

Coordination of balancing mechanisms

TenneT deals with imbalances on the transmission grid by using a single buyer balancing market. Instruments used by TenneT on these markets are frequency containment reserves (FCR), frequency restoration reserve (FRR) and replacements reserves (RR) (ECN, 2016). Primary frequency control is used for the FCR, and is known as 'Primaire Regeling' or primary control in the Netherlands. FRR instruments are used for frequency restoration. Automatically activated FRR, also referred to as secondary control and known as 'Regelvermogen' or regulating capacity is used for frequency restoration by continuous central activation by TenneT. Manually activated FRR, also referred to as tertiary control and known as 'Reservevermogen' or reserve capacity is activated by TenneT. In exceptional circumstances, during major or prolonged imbalances, a special form of manual FRR, emergency power or 'Noodvermogen' is activated by manual and discrete instructions of TenneT. Replacement reserves refer to the intra-day market and is out of the control of TenneT. Reserve capacity can also be used as a replacement reserve. The different balancing mechanisms are activated in subsequent order, from FCR, to FRR and finally RR. (DNV KEMA, 2013; SEDC, 2015; TenneT, 2016b)

BRPs are held financially liable for the deviations in their e-programme and actual production or consumption and are therefore incentivised to make an accurate estimation of their expected production or consumption. The providers of flexibility on the balancing market, except for providing primary control, are reimbursed by TenneT which allocate costs to the BRPs which fail in matching their e-programme. Provision of primary control is obliged to electricity producers with a production capacity of > 60 MW per unit (TenneT et al., 2011) and is not reimbursed for utilisation, but only for availability (DNV KEMA, 2013). Primary control is continuously controlled by information signals from TenneT (TenneT, 2016b).

Regulating capacity and reserve capacity are activated by TenneT on the principles of the merit order, where obligatory- (which are tendered yearly) and voluntary bids are ranked upon price. The bids with the lowest price will be activated first (TenneT, 2016b). Remuneration of the regulating capacity is therefore determined by the most expensive unit activated in a specific time unit (TenneT et al., 2011). Emergency power is contracted yearly and remunerated for their availability and utilisation (a minimum of 200 €/MWh) (TenneT, 2016a).

Technically, all transactions in the balancing market are managed centrally and real-time by the energy management systems of TenneT with data input from the electricity suppliers. For regulating and reserve capacity, the merit order subsequently determines which producers have to be activated. BRPs deviating from their e-programme are penalized by TenneT for not meeting their exact planned production or consumption. The deviation of BRPs between actual production or consumption and their e-programme is measured by the DSO. (TenneT, 2017a). An overview of the coordination of the balancing mechanism is provided in Table 4-2.

Table 4-2: Overview of the coordination of balancing mechanisms

Transaction	Technical coordination	Organisation of interaction
Primary control	Centrally managed by TenneT Automated activation based on frequency	Framework agreement Obliged by law Availability payment Weekly procurement of capacity

Regulating capacity	Centrally managed by TenneT Automatic activation Activated upon lowest bid price Optimised for each production time unit	Minimum capacity tendered yearly Contract tendered parties Obliged bids by tendered capacity Voluntary bids Availability payment Utilisation payment (marginal pricing)
Reserve capacity	Centrally managed by TenneT Manual activation by TenneT Activated upon lowest bid price	Voluntary bids Utilisation payment (marginal pricing)
Emergency power	Centrally managed by TenneT Manual activation	Yearly tender Contract tendered parties Availability payment Utilisation payment
Replacement reserves	Centrally managed by EPX	Intraday spot market Voluntary bids
Financial compensation	TenneT centrally coordinates transactions based on e-programmes and transactions on balancing market DSO measures actual electricity usage	Compensation schemes

Coordination of transmission- and distribution electricity transport transactions
Technically, the activity of transport services on both the transmission and distribution network is highly centralised, because of closed access and assigned responsibility to TenneT and the DSOs. The connection to both the transmission- and distribution network to enable transport services is also coordinated in a centralised way. Parties connected to, and using the transmission network of TenneT pay a connection fee and a transmission fee which covers the costs of the installation, maintenance and replacement of a connection to the transmission grid and transmission services respectively (TenneT, 2017e). Tariffs on the distribution network are characterised by a similar structure as is observed in the transmission network (Stedin, 2017c).

Coordination of final small consumer consumption
The electricity demand of the final consumer acquires the amount of electricity flowing from the producers to the end consumer via transmission and distribution (de Vries et al., 2010). From both a technical- and economic perspective, electricity suppliers coordinate the transaction of final energy consumption from the perspective of the final consumer. Electricity suppliers could essentially be considered as the intermediary of a group of consumers. Electricity suppliers act on behalf of their consumers on the EPX spot market or the bilateral market to guarantee the supply of the electricity to their consumers and establish contractual agreements with electricity producers after which electricity flows from producers to the consumers via transmission and distribution networks. The transmission and distribution is technically under control of TenneT and the DSO. Besides, the DSO is assigned with the connection of final consumers to the distribution grid and the measurement of electricity usage. Costs relating to the activities of transmission and distribution are passed on to the electricity supplier. Ultimately, the electricity supplier allocates all costs relating to the transaction of electricity supply on to the final consumer. The economic coordination between the final consumer and electricity suppliers is established by contractual agreements for a specified period of time. As the supply of electricity is a competitive activity, consumers are free to

choose their own electricity supplier and are allowed to switch between electricity suppliers at the end of a contract in effect.

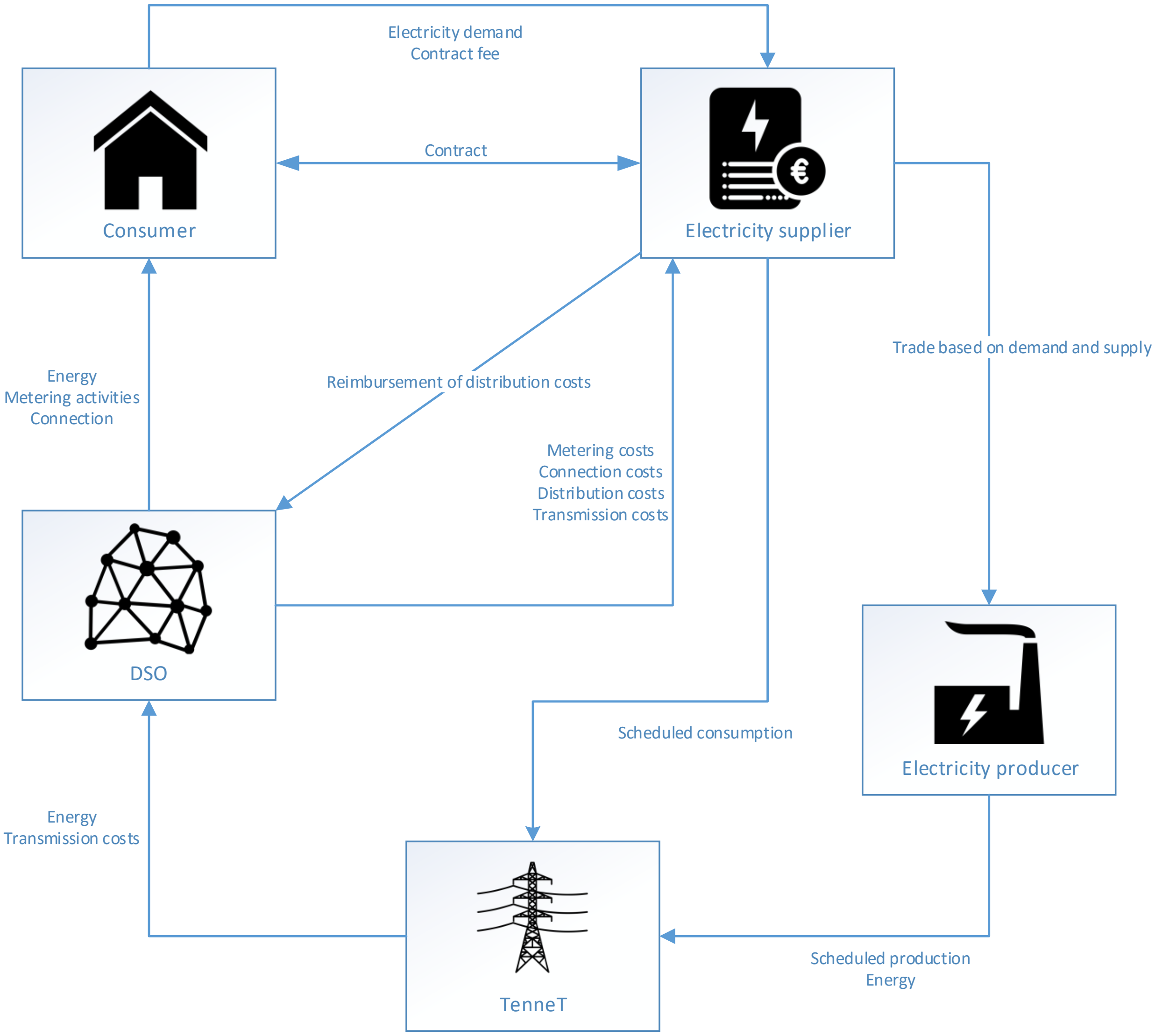

Figure 4-4: Highly aggregated overview of the coordination of final electricity consumption

Schematic overview

The analysis of the coordination within the current electricity sector has been summarised in the schematic overview in Figure 4-5.

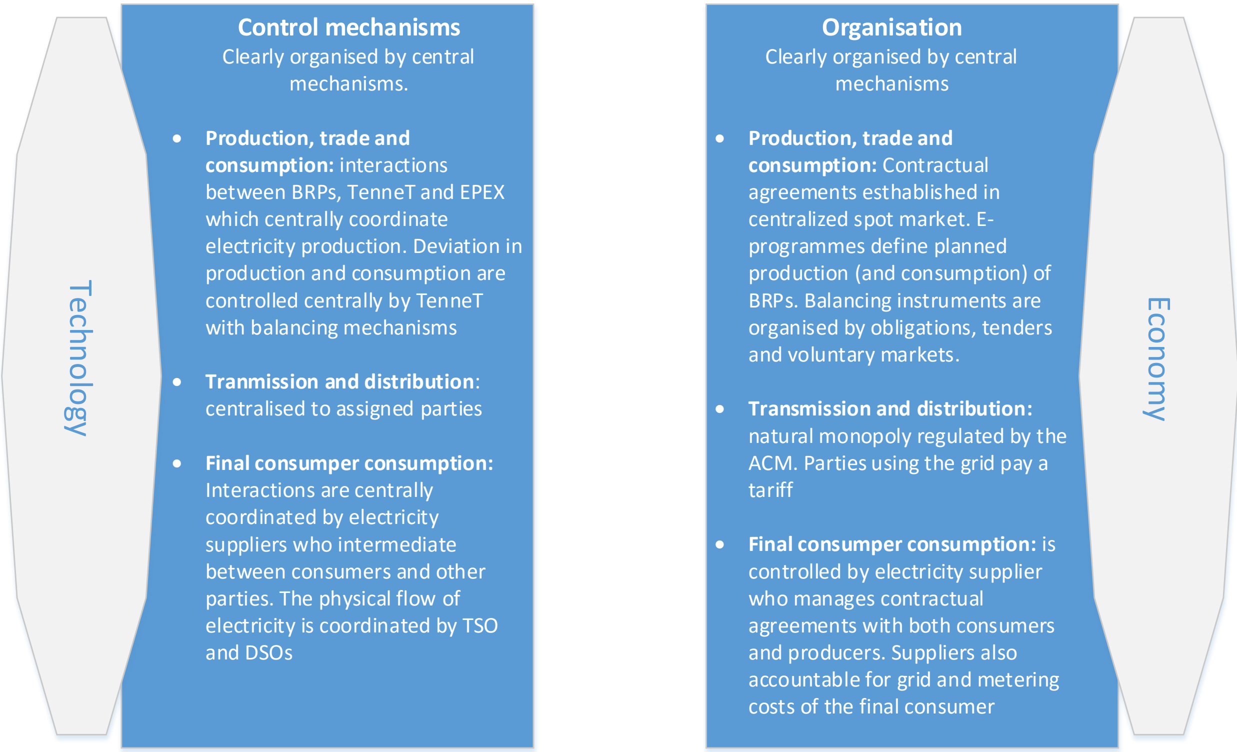

Figure 4-5: Schematic overview of control mechanisms and organisation

4.5 Lessons learned from the current design environment of the Dutch electricity sector

This section elaborates on the lessons learned from the perspective of the scope of this research by answering the sub-research question: *What are relevant characteristics of the Dutch electricity sector to be considered in the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?* This chapter provided an overview of the Dutch electricity sector by considering concepts as found in the CD framework. The sector is analysed in its entirety to keep track of challenges and opportunities of future aggregation systems throughout the entire sector.

From the analysis of the electricity sector it became clear that the upper layers as defined by the CD framework constrain and guide choices in the underlying layers. For example, the upper layers define transmission systems as a network with closed access in both the technical as institutional dimension, as it is characterised as a natural monopoly. This has its effect on the technical design principles and market governance structured along the responsibility design knob. As access is closed due to the natural monopoly characteristic, technical responsibility of transmission activities and the coordination of transmission activities is completely within the hands of TenneT. As the systemic- and institutional environment determine the underlying layers, the inclusion of a future aggregation system should not totally redefine the current systemic- and institutional environment. As Scholten and Künneke (2016) point out, the design or integration of a new technology in an energy infrastructure should fit in with the current systemic or institutional environment. A future aggregation system should therefore comply with the current perceptions as found in the systemic- and institutional.

The goal of this chapter was to identify the concepts of the design environment to be able to map implications relating to the environment of the electricity sector. Different activities and parts of the electricity sector are structured differently depending on their characteristics. In the systemic- and institutional environment access is open to those activities that have a competitive character and access is closed for those activities which are characterised as a natural monopoly. The layer of access is currently characterised by a centralised dominancy. In the layer of responsibilities a clear distribution in responsibilities, ownership and decision rights can be observed. This layer is also characterised by a centralised tendency with a dominancy by central established parties and markets. The centralised tendency is also observed in the layer of coordination where central mechanisms and central established parties are in charge of coordinating electricity sector activities. The main notion as found in this chapter is therefore that the most relevant aspect to consider in the analysis of design implications is the centralised tendency in both the engineering- and institutional perspective. This chapter provides viable information that is used as input for the detailed analysis of design implications in chapter 6.

5 Conceptualising the aggregator role and a blockchain application in unlocking decentralised flexibility

To be able to identify design implications for the aggregator and blockchain aggregation systems, it is necessary to get a better understanding of both the aggregator role and a blockchain application. This chapter explores both options by answering the third sub-research question, *How can the aggregator role and a blockchain application be conceptualised in the case of unlocking decentralised flexibility in the Dutch electricity sector?* In 5.1, there is elaborated on the comcepts of the aggregator, as well as the drafted configuration of the aggregator role in this thesis are discussed. Section 5.2 elaborates on the concepts of blockchain technology and the technical principles behind blockchain technology, and the drafted configuration of a blockchain application in the case of managing a flexibility model. As blockchain is perceived as a very complex technology, the concepts and features of blockchain technology have been discussed in more detail.

The USEF framework, a prevailing aggregator flexibility model in the Netherlands, is used as guidance for the conceptualisation of the aggregator role in this research. Such a theoretical model is non-existent for blockchain technology. The drafted configuration of a blockchain flexibility application is therefore derived from the concepts of the USEF framework and the concepts and features of blockchain technology.

5.1 Concepts of the aggregator

The aggregator role is considered as a market intermediary by providing the link between the supply and demand side of decentralised flexibility. This section elaborates on the general functionalities of intermediaries as described in the literature in 5.1.1. Section 5.1.2 elaborates on the more detailed concepts of the aggregator in a future flexibility model.

5.1.1 Functions of market intermediaries

The added value of intermediary roles is discussed in detail in literature. According to Giaglis et al. (2002), intermediaries play a broad role in traditional markets and the functioning of it. The main functions of intermediaries are the matching of buyers and sellers, the facilitation of transactions and the provision of an institutional infrastructure (Giaglis et al., 2002). Bailey and Bakos (1997) discusses four functions of intermediaries in markets. The first is the aggregation of buyer demand and seller supply in order to achieve the most efficient economic solution in terms of economies of scale and scope and to reduce the costs relating to contracting activities. The second is to provide a base of trust to buyers and sellers and to protect both buyers and sellers from opportunistic behaviour. The third is to facilitate the market and reduce operating costs. The fourth and final function is matching of buyers and sellers. Spulber (1996) also acknowledges four intermediary functions: the clearing of markets, price setting, providing liquidity and immediacy, the coordination of buyers and sellers and the guarantee of quality and monitoring of performance.

Reflecting on the functions and roles of intermediaries, many intermediaries can be recognized in the current electricity sector. Basically all parties in the supply chain which are not directly involved in the production or consumption can be classified as an intermediary. The TSO, DSOs, electricity suppliers and EPEX Netherlands can all be seen as intermediaries. All intermediaries fulfil the functions as described in the above to a certain extent. The table below (Table 5-1) provides an overview of the functions of intermediaries in the electricity sector.

Table 5-1: Reasons for the presence of intermediaries in the electricity sector, linked with functions described in literature

	Aggregation & Matching	**Trust**	**Facilitating**	**Institutional infrastructure**
TSO	Natural monopoly is the most efficient economic organisation	Reducing opportunistic behaviour on a critical infrastructure	Electricity markets Transmission services Physically aggregate and match the demand and supply of electricity	Legal basis to operate network
DSOs	Natural monopoly is the most efficient economic organisation	Reducing opportunistic behaviour on a critical infrastructure	Distribution services Physically aggregate and match the demand and supply of electricity	Legal basis to operate network
EPEX	Reducing transaction cost with wholesale platform	Reducing opportunistic behaviour by using predefined trade platforms	Reduce operating costs by using the digital automatic market settlement	Legal basis to organise wholesale markets
Electricity suppliers	Reducing transaction costs by trading on behalf of small consumers	Ensuring supply of a public good	Reducing operation costs by trading on behalf of a group of small consumers	Legal basis to operate on wholesale markets

The aggregator concept can be defined as the intermediary between consumers willing to provide decentralised flexibility, and actors in the electricity sector willing to make use of the flexibility provided by prosumers (Ikäheimo et al., 2010; Lynch et al., 2016; Sandels et al., 2011). define four functions of intermediaries in the case of a future aggregator: information management, the bundling of services, matching and market clearing, and transaction guaranteeing.

5.1.2 A proposed configuration of the aggregator in unlocking decentralised flexibility

Considering the functions as described by Eid et al. (2015), aggregators should be able to provide the functions of information management, aggregating the demand and supply of flexibility, facilitating market clearing and transactions and provide a system of trust between buyers and sellers of flexibility. The USEF framework (USEF, 2015), a framework proposing an universal design to unlock decentralised flexibility provided by prosumers to BRPs, DSOs and the TSO with the intermediation of an aggregator. USEF acknowledges a central role for the aggregator in unlocking decentralised flexibility, aggregating prosumer flexibility, creating flexibility portfolios and the offering of flexibility portfolios into the market. Consumers of flexibility reimburse the aggregator for the flexibility service where the aggregator subsequently passes a fee on to the prosumers. A schematic overview of this concepts is shown in Figure 5-1. Other literature that focusses on the design of the aggregator role in providing flexibility services, such as Ikäheimo et al. (2010) and Smart Grid Task Force (2015) present a similar configuration in terms of interaction and coordination as USEF.

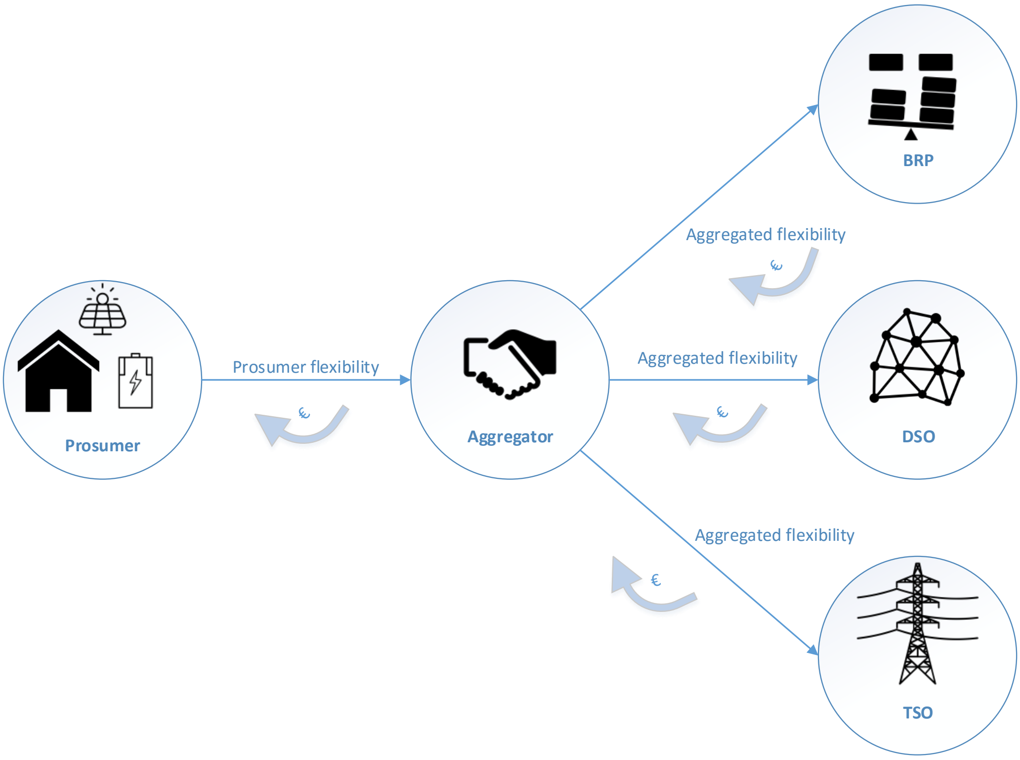

Figure 5-1: The central role of the aggregator in unlocking decentralised flexibility (adapted from USEF (2015))

5.1.2.1 Market interaction in the aggregator model

USEF provides a comprehensive list of flexibility- products and services. Services that the aggregator can provide to the BRP are day-ahead optimisation, intraday optimisation, self-balancing and generation optimisation. For the DSO, the aggregator can provide grid management services such as congestion management, voltage control, grid capacity management, redundancy support and power quality support. The services on the level of the TSO provided by the aggregator are balancing services such as primary control, secondary control, tertiary control, capacity on capacity markets, congestion management, grid capacity management and redundancy support.

Focussing on the flexibility products as described above, several interactions in the markets between involved stakeholders can be identified. In Figure 5-1, a direct relation between the aggregator and the TSO have been drawn. In the proposed market interaction however, flexibility from the aggregator to the TSO is offered through the BRP. A complete overview of market interaction with the introduction of USEF is provided in Figure 5-2.

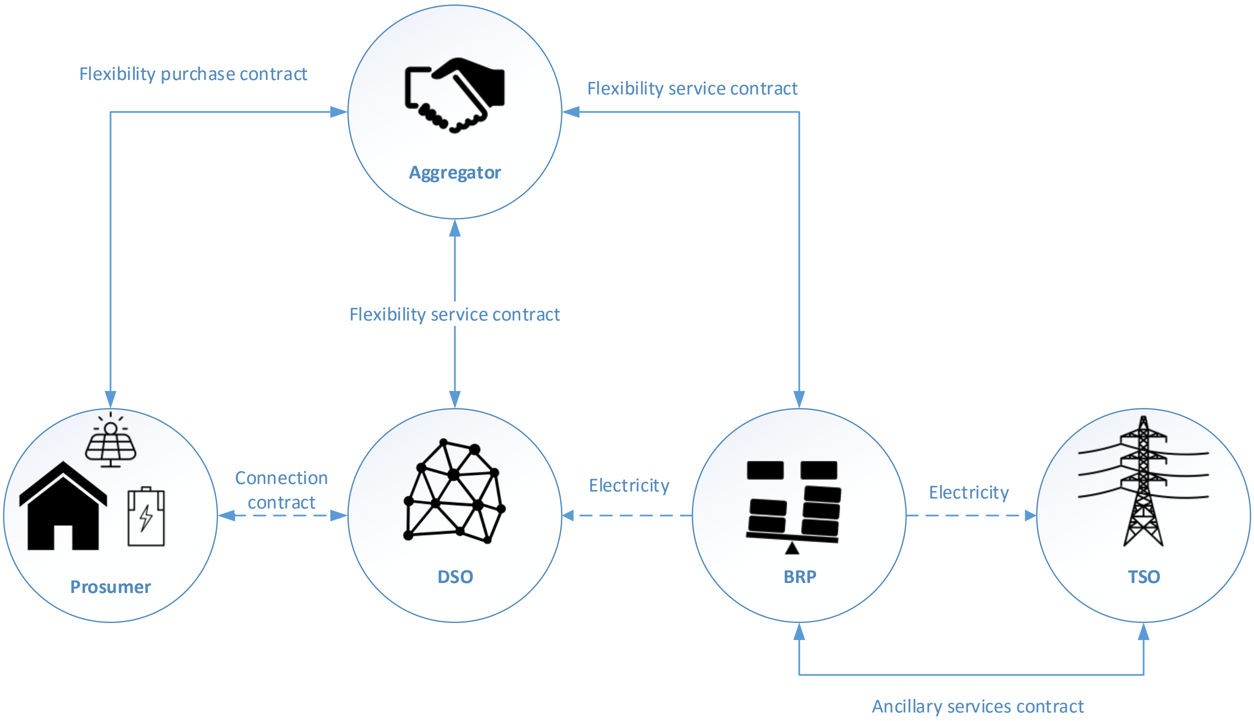

Figure 5-2: Market interaction with the introduction of an aggregator based on the USEF framework (adapted from USEF (2015))

5.1.2.2 Market coordination in the aggregator model

The market coordination of the aggregator role as proposed by USEF, consists out of five stages; contract, plan, validate, operate and settle. The contracting phase involves defining the contracts between the aggregator and flexibility supplying and demanding parties as shown in Figure 5-2. The other coordination steps are discussed in more detail in the section below (subtracted from USEF (2015)).

Planning

Planning is the phase where the aggregator defines a flexibility portfolio, which can be compared with a BRP E-programme. Subsequently, the BRP optimises its portfolio of aggregators, producers and suppliers. Depending on the outcome of its portfolio, the BRP negotiates with the aggregator to make flexibility available at a certain time slot. The expected acquired flexibility is included in the E-programme of the BRP, which is offered to the TSO. The process of planning is rather complex with a lot of transactions involved. The prosumer needs to communicate its forecasted available flexibility and pre-defined preferences to the aggregator. The aggregator has to collect forecasted information, create and optimise its portfolio, communicate its flexibility plan to the BRP and trade flexibility with the BRP. The BRP has to optimise its portfolio partly based on the aggregator flexibility plans and request the aggregator for a certain amount of flexibility at a certain time slot.

Validate

This phase comprises the step in which the DSO and TSO check the E-programmes on grid constraints. The aggregator iterates its initial proposed flexibility plan. When grid congestion occurs, the DSO can procure flexibility from the aggregator to obviate this from happening. The flexibility plan of the aggregator needs to be defined in such a way that the aggregator flexibility plan aligns with the DSO and TSO grid constraint analysis.

Operate
This phase comprises of the actual delivery of electricity and flexibility. As in the current electricity system, deviations from agreed programmes can occur due to system imbalances, congestion or deviations from the flexibility programme. Depending on the actor affected by a deviation, that specific actor has to adjust its portfolio position.

Settlement
In the settlement phase, the flexibility transfer between different actors in the value chain of flexibility is established. The aggregator in this phase ensures market clearing and the guarantee of transactions. Settlement is performed between the prosumer and aggregator, between the BRP and the aggregator, and between the DSO and the aggregator.

5.2 Blockchain – The concepts behind blockchain technology

Blockchain is perceived as a rather controversial concept compared to the aggregator role. Where on the one hand the aggregator centralizes the power of transaction and management of transactions to a central party, blockchain on the other hand is based on the power of decentralisation. A transaction refers to the transfer of an asset. In a flexibility model making use of blockchain technology a transaction refers to the transfer of a certain amount of flexibility and a fund paid for the flexibility. This chapter discusses the technology and concepts behind blockchain and the design of a flexibility model based on blockchain technology. Section 5.2.1 till section 5.2.6 elaborates on the specifics of blockchain technology, section 5.2.7 discussed the increasing interest of blockchain in the energy sector by elaborating on use cases in the energy sector, and section 5.2.8 conceptualises the blockchain application in unlocking decentralised flexibility.

5.2.1 Characteristics of blockchain technology

Blockchain is a disruptive technology introduced to the world with the introduction of Bitcoin. by Nakamoto (2008) The unique characteristic of blockchain, compared to a classic intermediary role, is the ability of decentralising and distributing the management of transactions whilst maintaining reliability (even in the presence of unreliable participants within the network) (Watanabe et al., 2016). Blockchain enables for a distributed ledger which rules out the need for a third party intermediary. The first conceptualisation of a blockchain application is Bitcoin, a peer-to-peer cash system which enables online payment transactions without the interference of a financial institution (bank) (Nakamoto, 2008). Figure 5-3 and Table 5-2 provide an insight on how blockchain technology is expected to disrupt the management of transactional systems. The main advantage of using blockchain technology is that it reduces the need for trust between stakeholders, builds a secure value transfer system, increases record transparency and ease of auditability, and can streamline business processes across multiple entities (Hileman & Rauchs, 2017). Blockchain however is not a one size fits all solution. In the optimal solution, it is implemented in systems with a significant number of participants that are in need for a transparent trusted network.

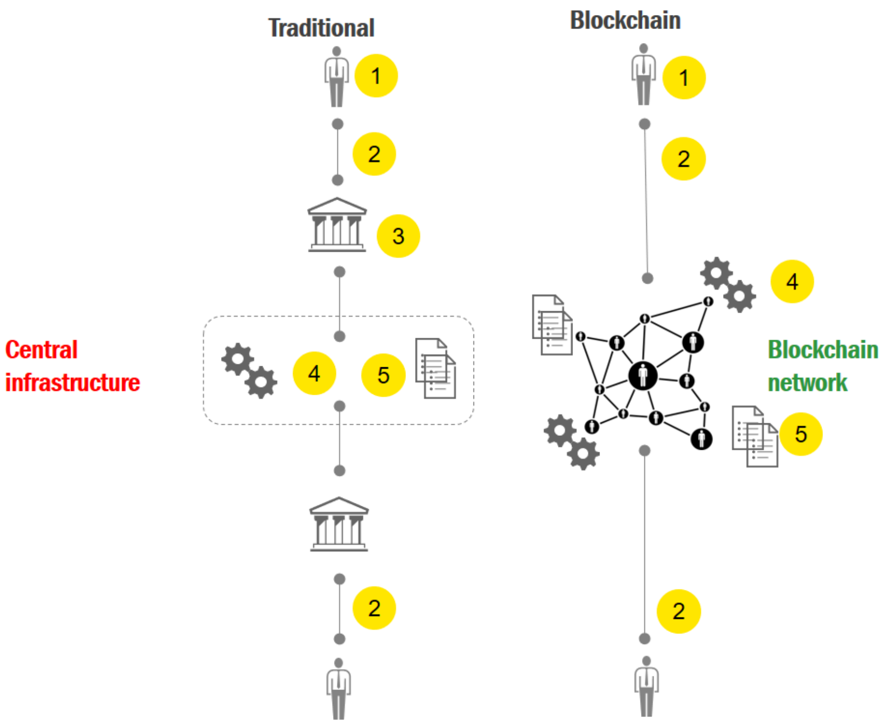

Figure 5-3: The redundancy of an institutional organisation with the introduction of blockchain technology (EY, 2017)

Table 5-2: Different activities in the transaction process: traditional networks vs. blockchain networks (abstracted from (EY, 2017))

	Purpose	**In traditional networks**	**In blockchain networks**
1 Front end	Node or user which triggers the transaction	Remains the same, though Internet of Things is likely to increase and diversify the number of machine nodes	
2 Messaging	Technical connectivity with the ledger	Through central infrastructure	Peer-to-peer
3 Institutional party	Own and administer the transaction	Centrally with cost added to transaction price	Redundant as transaction owner
4 Processing	Execution of agreed action	Centrally per batch or per transaction	Distributed and pre-programmed
5 Ledger	Auditable repository or database	Central and closed access. A trusted centralised party manages the ledger	Multi-partial and decentralised. Ledger is encrypted.

5.2.2 The process of transactions in blockchain technology

Blockchain technology provides reliability in decentralised transactions by solving the double-spending problem which arise in digital peer-to-peer transactions (Nakamoto, 2008). In a physical transaction, for example trading a banana on a grocery market, no problems relating to double-spending arise. A buyer can physically check whether the banana is available to him and not traded before and when the customer pays with cash, no questions whether this money is spent before arise. When the banana is paid by card, the bank (as the intermediary) checks whether the money is not spent before. In the case of Bitcoin, blockchain technology solves for the double-spending problem by combining BitTorrent peer-to-peer file sharing technology in combination with public key cryptography which enables trusted transaction without the need for intermediation (Swan, 2015).

The blockchain network is built upon several technical elements that enable reliable transactions. The blockchain network, as the name already suggests, consists out of a chain of blocks. Blocks contain a list of data records wherein transactions are recorded. Blocks within the blockchain are characterised by the block header and the specific content of the block. The block header contains general metadata such as a reference number, a time-stamp and its linkage in the blockchain (a link with the previous blocks in the blockchain). The block content contains a list with validated assets and instruction statements referring to transactions made (Deloitte, 2016). Transactions are recorded in the blockchain by the following steps as described by Nakamoto (2008) and Froystad and Holm (2016) (see also Figure 5-4):

1. A new transaction is created and transmitted to the network by the sender. The transaction entails details of the receiver of the transaction and a cryptographic digital signature that proves the authenticity of the transaction. The transaction is then subsequently send to all nodes in the network for validation.

2. Each node collects new initiated transactions and checks the authenticity of the transaction by decrypting the digital signature.

3. A block is created which consists out of a series of transactions. The block is subsequently updated in the public ledger.

4. The nodes in the network receive a new block for validation. This is performed by some sort of consensus mechanism. The leading consensus mechanism used in blockchain application is ‘proof-of-work’. In proof of work, new blocks are validated only if the majority of nodes of the network acknowledge the validity of the block. Nodes only accept the entire block if all transactions in the block are valid and authentic.

5. Once validated, the new block is connected to the previous block in the blockchain. This connection is established by using a hash (see next section) for the new block and the hash of the previous block.

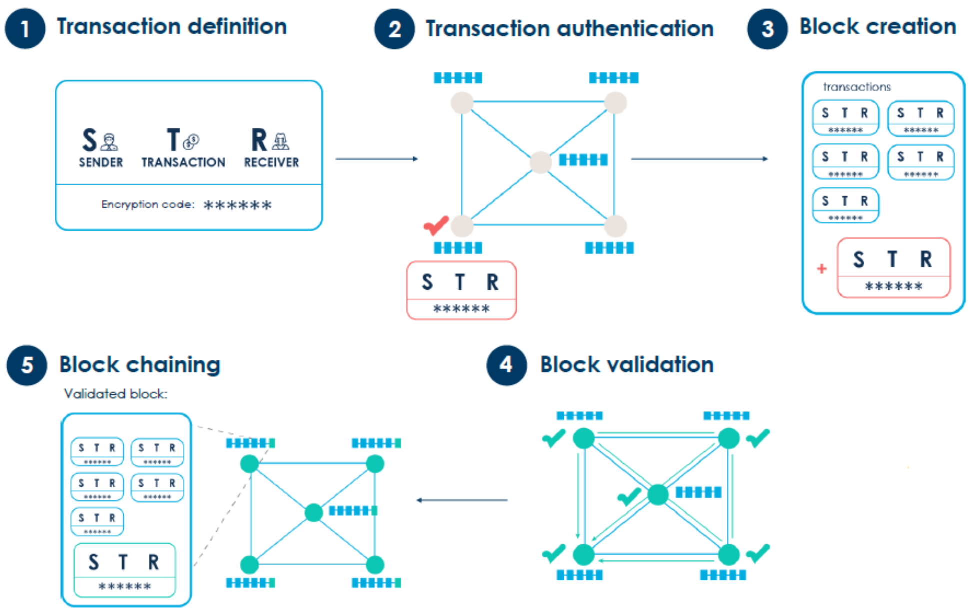

Figure 5-4: The process of the registration of a transaction on the blockchain (Froystad & Holm, 2016)

5.2.3 Blockchain technical concepts relating to cryptographic proof and consensus methods

Trust within the process of transactions is traditionally provided by third party intermediaries. Within the concepts of blockchain, trust is provided by cryptographic proof. Cryptographic proof in the blockchain is provided by making use of hash functions, public-key cryptography and digital signatures. As described in 5.2.2, once transactions are authenticated by the cryptographic proof, the transaction is placed in a block and subsequently blocks are placed on the blockchain once validated by a specific consensus method. This subsection provides an overview of the most important technical concepts relating to cryptographic proof and it provides a short description of different consensus methods used in blockchain applications.

Hash functions

A hash function is a computation algorithm which transforms the data of a transaction (document) being transferred on the blockchain into a hash, a string of 64 characters. The generated hash represents the content of the original data file. The hash is unique for the data it represents and only the slightest change in the original data file will generate a complete different hash output. An interesting feature of hash function is that the same data always leads to the same hash function, it is however practically impossible to trace back the data from a particular hash function. The hash function enables every document to be encrypted for transmission since the hash of a document only exists out of 256 bits, which solves for the maximum file size of encryption. (Swan, 2015)

Private- and public encryption keys

In blockchain, encryption is performed by public-key cryptography. Two keys are relevant within public-key cryptography, the so-called public- and private key. The private key belongs to an individual node and should be kept secret at all times. The public key is derived from the private key and sent to all recipients. The hash generated by the hash function is encrypted by the private key. Only the node with access to the right public key can decrypt the hash encryption to access information as displayed in the original document. (EY, 2017; PWC, 2016a; Swan, 2015)

Digital signatures
The digital signature protects the validity of the transaction on the blockchain by combining the concepts of hash functions and private and public encryption keys. The encrypted hash is also referred to as the digital signature. The digital signature is sent along with the digital document. The recipient therefore has access to the digital document that has been sent, the digital signature and the public key. (EY, 2017)

Signature validation
In performing cryptographic proof, the creation and the validation of the digital signature are the two most important steps (see Figure 5-5 and Figure 5-6 for a schematic overview). To summarise, the sender of a specific transaction generates a hash value of the information or asset the sender wants to send to the recipient by using a hash function. Subsequently, this hash value is encrypted by the private key. The recipient generates a hash value (hash value A in Figure 5-6) by decrypting the digital signature with the public key of the sender. Besides, the recipient hashes the received document with the same hash function as used by the sender to generate a second hash value (hash value B in Figure 5-6). When there is a match between hash value A and hash value B, it can be assured that the transferred data originates from the original sender and that the data transferred has not been altered during the transfer of information.

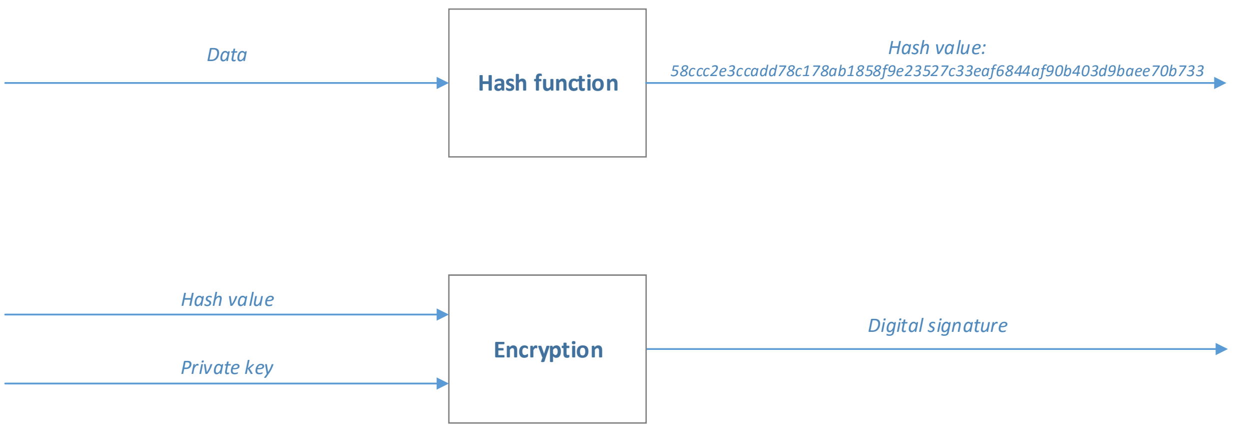

Figure 5-5: The creation of a digital signature in blockchain

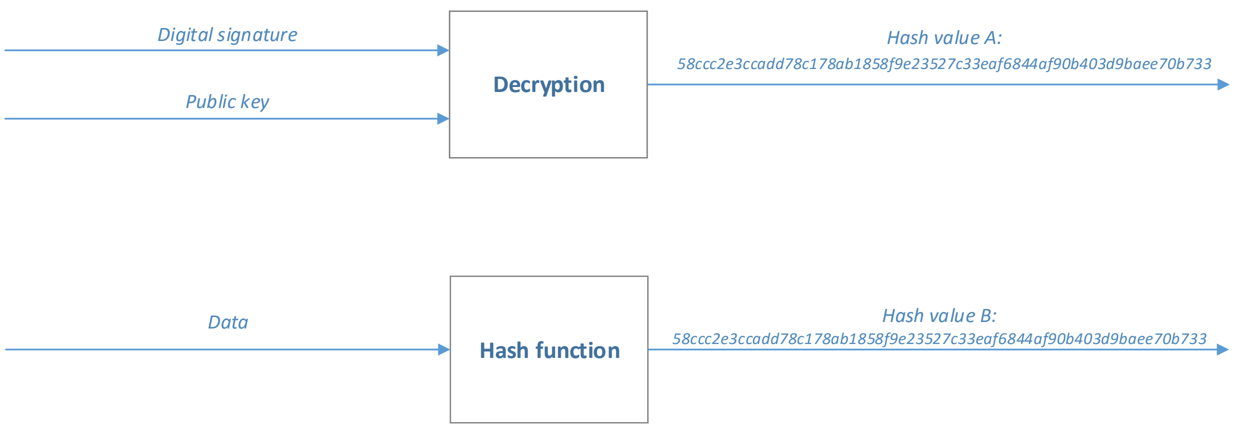

Figure 5-6: The verification of digital signatures in blockchain

Consensus methods
Once a transaction is authenticated, computing work is performed by the so called validator nodes to chain the transaction block in the blockchain network. Several consensus methods to exist. Most known methods are proof-of-work (used in Bitcoin and Ethereum) and proof-of-stake (believed to be used in the future by the Ethereum blockchain).

Proof-of-work is the consensus method as developed by Nakamoto (2008). In proof-of-work, blocks are accepted on the basis of majority rule. When 51% of the validator nodes in the network validate a block, the block is accepted on the blockchain. Proof-of-work makes use of network validators, so-called miners, that verify a block before it is placed in the blockchain. Data in the blocks is verified by using the hash of all transactions in a block. This hash is then placed in the header of the block. New implemented blocks also store a hash of the header of the previous block in its own header, which basically creates the linkages between chained blocks in the blockchain. Within proof-of-work, miners are continuously verifying the hashes of the transactions in a block by verifying whether the hash of the block and the hash of the previous block correspond to the previous update of the blockchain. The new block is created and coupled with the blockchain once the mining is completed and by the majority of the network is verified. As, proof-of-work is continuously checking the transactions in the network, the process is very energy intensive. (EY, 2017; Nakamoto, 2008; PWC, 2016a)

Proof-of-stake simplifies the mining process compared to the principles of proof-of-work. Instead of miners within the network verifying all transactions within the entire network, proof-of-stake users have to provide proof of their own stake in transaction.. Depending on the stake a user owns of the total blockchain assets, the user has to perform a certain percentage of the mining activity. When a user for example owns 5% of the assets, the user has to perform 5% of the total required mining work. As the total performed mining activity significantly reduces, total energy usage reduces as well in the proof-of-stake consensus method. (PWC, 2016a)

5.2.4 The different typologies in blockchain technology

An important distinction of different types of blockchain applications can be made based on their typology. Bitcoin is perceived as a blockchain application open for anyone willing to participate. This is also referred to as a public blockchain. As the decentralisation of power and control to its users was the main aim of the first initiated blockchains, the first generation of blockchain can be characterised as public blockchains. Concepts relevant to blockchain typology are permissionless and permissioned and public and private blockchains as elaborated on in Table 5-3.

Table 5-3: Definitions of blockchain typology as found in the literature

Reference	Typology	Definition
Buterin (2015)	Public	The blockchain is open and anyone is allowed to check information of transactions on the blockchain and perform transactions themselves. Besides, anyone can participate in the process of consensus. These types of blockchains are considered as fully decentralised blockchains.
	Private	In this type of blockchain, the creation on the blockchain is centralised to one organisation and the permission to read the blockchain may be either public or restricted.
	Consortium	This type of blockchain refers to a typology where a pre-selected set of nodes are assigned with the responsibility to control the

		consensus process. The permission to read might be public or restricted to participants.
BitFury Group (2015)	Public	A blockchain without any restrictions regarding to reading information and submitting transactions.
	Private	A blockchain where access to data on the blockchain and submitting transactions is limited to a set of entities.
	Permissionless	A blockchain with no restrictions in the validation process.
	Permissioned	A blockchain where the validation process is only allowed by assigned entities.
Deloitte (2016)	Public	Anyone willing to, can read data or write data to the ledger.
	Private	Participants of the blockchain are determined at front. Only those who are defined as participant are allowed to update the ledger.
EY (2017)	Public	Users are anonymous and own a copy of the ledger. All users are allowed to participate in confirming transactions independently.
	Private	Users are not anonymous and need permission for consulting the ledger and participation in transaction confirmation.
Froystad and Holm (2016)	Permissionless public blockchain	Access to the network is open to anyone. The validation is performed by anonymous, fully decentralised validators.
	Permissioned private blockchains	Access to the network is only authorized to some entities. Validation is performed by pre-selected trusted validators.
PWC (2016a)	Public	Participants are anonymous and access is allowed to all players willing to participate.
	Private	Users can only access the blockchain when they are granted with access.
Walport (2016)	Permissionless	Blockchains that are open to anyone willing to contribute.
	Permissioned	Only a selection of entities own the ledger, are allowed to contribute data, and verify the contents on the ledger.
Hileman and Rauchs (2017)	Public permissionless	Open to anyone to read, write on and validate transactions
	Public permissoned	Open to anyone to read, but only authorised participates are allowed to write to the blockchain. Validation might be open or restricted to authorised participants
	Consortium	Reading of- and writing to the blockchain is restricted to an authorised set of participators. Validation of the blockchain can be open or authorised to participants.
	Private permissioned	The reading of the blockchain is restricted to a limited set of nodes. Writing and validation is only allowed by the network operators

As can be observed from the literature describing blockchain typology, public and permissionless, and private and permissioned blockchains are somewhat used interchangeably and complement to each other. Only BitFury Group (2015) makes a full distinction between public, private, permisionless and permissioned blockchains. Using their definition, the public- and private axis refers to who is allowed to perform the actual transaction on the network and the permissionless- and permissoned axis of blockchain topology refers to who is allowed to perform transaction validation. Considering these definitions, four options in the design of a blockchain typology, public permissionless blockchains, public permissioned blockchains, private permissionless blockchains and private permissioned blockchains, exist. Private permissionless blockchains however do not make sense since it put restrictions on who has access to data or who may execute transaction on the blockchain but not on who is allowed to be involved in the consensus.

Public permissionless blockchains refer to the idea of full decentralisation. In this type of blockchain, no restrictions relating to reading, submitting transactions or the validation of transactions is present. This type of blockchain is visualised in Figure 5-7, in which the green nodes refer to a validator node which can both initiate and validate transactions.

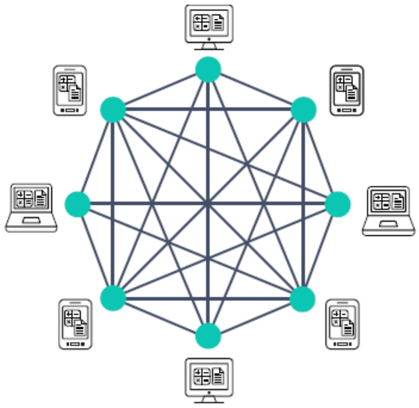

Figure 5-7: Public permissionless blockchain typology (abstracted from (Froystad & Holm, 2016))

Public permissioned blockchains are restricted blockchains from both the perspective of initiating and validating transactions. Buterin (2015) refers to this as consortium blockchains. The validation in this type of blockchain is only allowed by those who are selected a priori. This type of blockchain is visualised in Figure 5-8 where a green node refers to a validator node which can both initiate and validate transactions and a red node refers to member nodes, those who can only initiate transactions and **not** validate them.

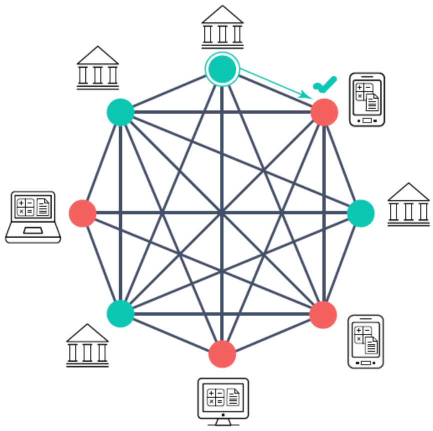

Figure 5-8: Public permissioned blockchain typology (abstracted from(Froystad & Holm, 2016))

Private permissioned blockchains differ from public permissioned blockchains, since in the private permissioned blockchain restrictions are placed on both reading and initiating transactions and the validation of transactions. This type of blockchain is visualised in Figure 5-9 where the green nodes refer to a validator node which can both initiate and validate transactions and red nodes refer to member nodes, those who can only initiate transactions and **not** validate them. The red line corresponds to the restricted access to the blockchain itself.

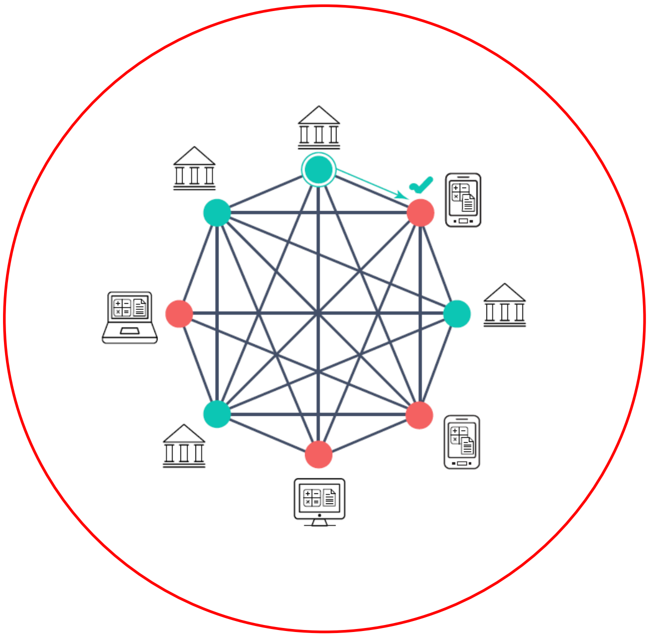

Figure 5-9: Private permissioned blockchain typology (adapted from (Froystad & Holm, 2016))

5.2.5 The maturity of blockchain technology

Financial and cryptocurrency blockchains like Bitcoin, which cause the decentralisation of money and payments are also referred to as blockchain 1.0 (PWC, 2016a; Swan, 2015). Blockchain 1.0 is however quite limited for applications beyond cryptocurrencies. Currently, blockchain 2.0 is in full deployment. Blockchain 2.0 is focussed on the decentralisation of markets in general and it enables the decentralisation of contracts by the introduction of so-called smart contracts. Smart contracts in blockchain 2.0 enable the execution of predefined transactions (contracts) without the interference of a third party (PWC, 2016a). Because of the disintermediation transaction can be executed automatically and anonymously. The smart contract is coded in the blockchain and can automatically execute transactions as predefined in the smart contract (Swan, 2015). Blockchain 3.0 will focus on the more detailed development of the principles of smart contracts and the adding predictive analytics which should enable decentralised autonomous organisations (PWC, 2016a).

5.2.6 The implication of blockchain technology on institutions

Blockchain can be considered as a very disruptive technology, but it also restructures our thoughts on institutions, and how we could think about organisations and coordination (Davidson et al., 2016; MacDonald et al., 2016). The main added value of blockchain technology is that it provides new ways of organising transactions between parties, which allows for decentralising power. Following transaction cost economics, the most efficient situation is achieved once the costs of coordinating transactions is minimised (North, 1990). Trust leads to better performance in terms of transaction costs, since activities in audits and risk allocation diminished. Considering a ledger, currently trust is maximised by centralising it to a trusted party such as a bank. However, many complexities are involved in managing a centralised ledger. Blockchain undermines current hierarchies and relational contracting by distributing the ledger (Davidson et al., 2016). In the end this could lead to increasing the cost effectiveness of the transaction (MacDonald et al., 2016).

5.2.7 Blockchain energy use cases

Blockchain technology can help various segments in the current centralised electricity sector. Many use cases, however still very small scale, of blockchain applications in the electricity sector are evolving at this moment. To provide insight in blockchain use cases evolving in the energy sector, an overview of relevant use cases is provided in Table 5-4.

Table 5-4: Overview of blockchain use cases in the electricity sector

Project	Project description	Blockchain principle	Blockchain enables…
Brooklyn Microgrid (Brooklyn Microgrid, 2017)	The use of blockchain to enable the peer-to-peer energy trade of excess solar energy.	Smart contracts carry out transactions	Trust and security Empowerment of prosumers
Slock.it EV charging (Slock.it, 2017)	Operate the charging of electric vehicles with the support of blockchain	Smart contracts carry out transaction	Trust and security Empowerment of consumer Autonomous response
Oneup POWR (PWC, 2016a)	Decentralised energy transaction	Smart meter in connected to a Raspberry Pi which in real-time monitors and executes smart contracts	Trust and security Empowerment of prosumer
Grid singularity Green Energy Tracking (EY, 2017)	Tracking origin of energy to monitor amount of green energy	Blockchain records volume of green energy used/generated	Trust Consumer confidence
Electron Smart Meter Data and Management (EY, 2017)	Blockchain records electricity flow through smart meter	Blockchain facilitates real- time monitoring of consumption, control and optimisation.	Real-time electricity demand and supply Smart meter data management
Alva POC (Alliander, 2017)	Blockchain enables the trade of energy in both peer-to-peer energy and the wholesale market	Smart meter is connected to blockchain. Smart contracts are used for procurement with variable energy prices, energy transactions with flexible transport tariffs and enforcing grid rules	Real- time settlement

Following Table 5-4, EY (2017) and (C. Burger et al., 2016) the conclusion can be made that blockchain could play a role in many segments in the electricity sector: EV charging optimisation, distribution system management, asset and commodity management, peer to peer trading, peer to market trading, energy optimisation behind the meter, trading platforms, decentralised generation, and data management and transfer.

5.2.8 A proposed configuration of a blockchain application in unlocking decentralised flexibility

Where the role of the aggregator in unlocking a decentralised flexibility model is broadly researched on, research on blockchain applications in unlocking decentralised flexibility is rather unexplored. Considering the concepts of blockchain technology as discussed in the previous parts of 5.2 and the elements as described in the aggregator role in the USEF framework, a conceptualisation of the flexibility blockchain application has been made (see Figure 5-10 for a schematic overview)

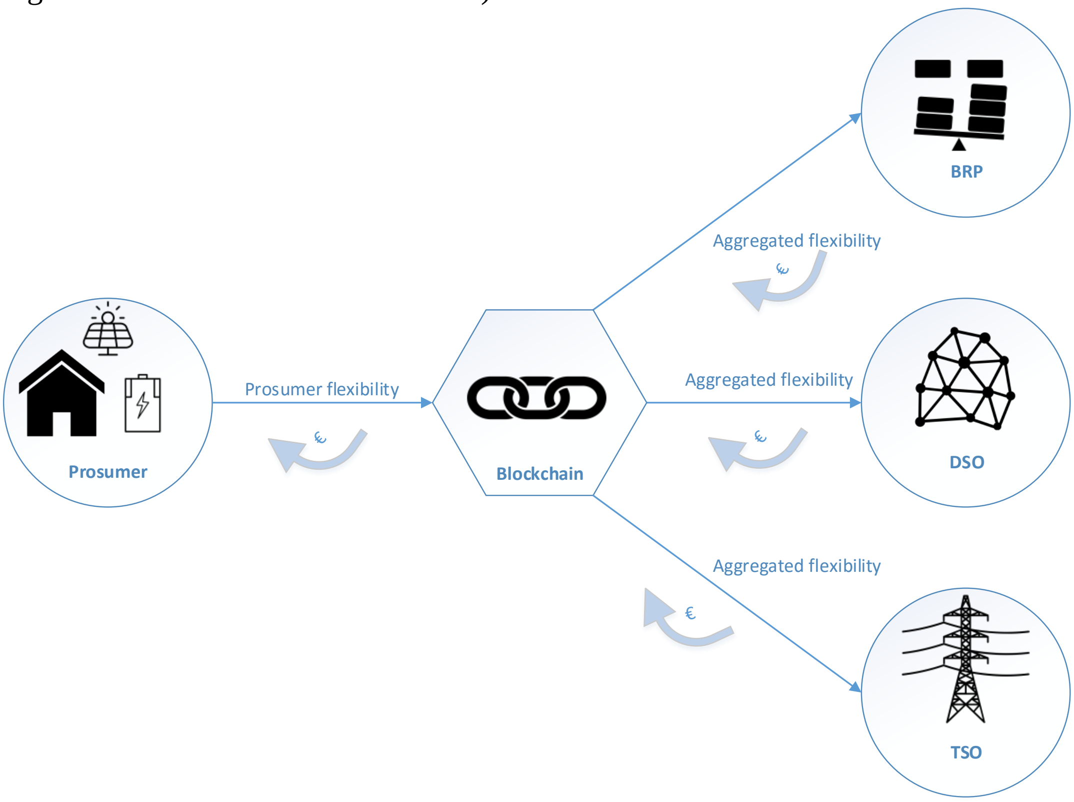

Figure 5-10: A blockchain application as mode of interaction in unlocking decentralised flexibility

Interaction and coordination of the blockchain technology is very different from the case of the aggregator. In the case of a blockchain application, there is no need to establish mutual contracts between interdependent actors, as is the case for the aggregator. Smart contracts and the concepts of blockchain 2.0 can take over the role of mutually agreed contracts, in which smart contracts could automatically execute predefined agreements. For example, if Alice defined in a smart contract that she could sell flexibility of amount x for a price y, and Bob wants to buy a certain amount of flexibility which is within the threshold of price y, the smart contract automatically executes the operational- and economical transaction. The smart meter of the prosumer then monitors how much electricity is fed in into the distribution grid and secures this in the blockchain ledger. This implies that the interaction between stakeholders differs from the case where the aggregator centrally manages contracts. The contracting interaction in the case of supplying flexibility by means of a blockchain application is shown in Figure 5-11.

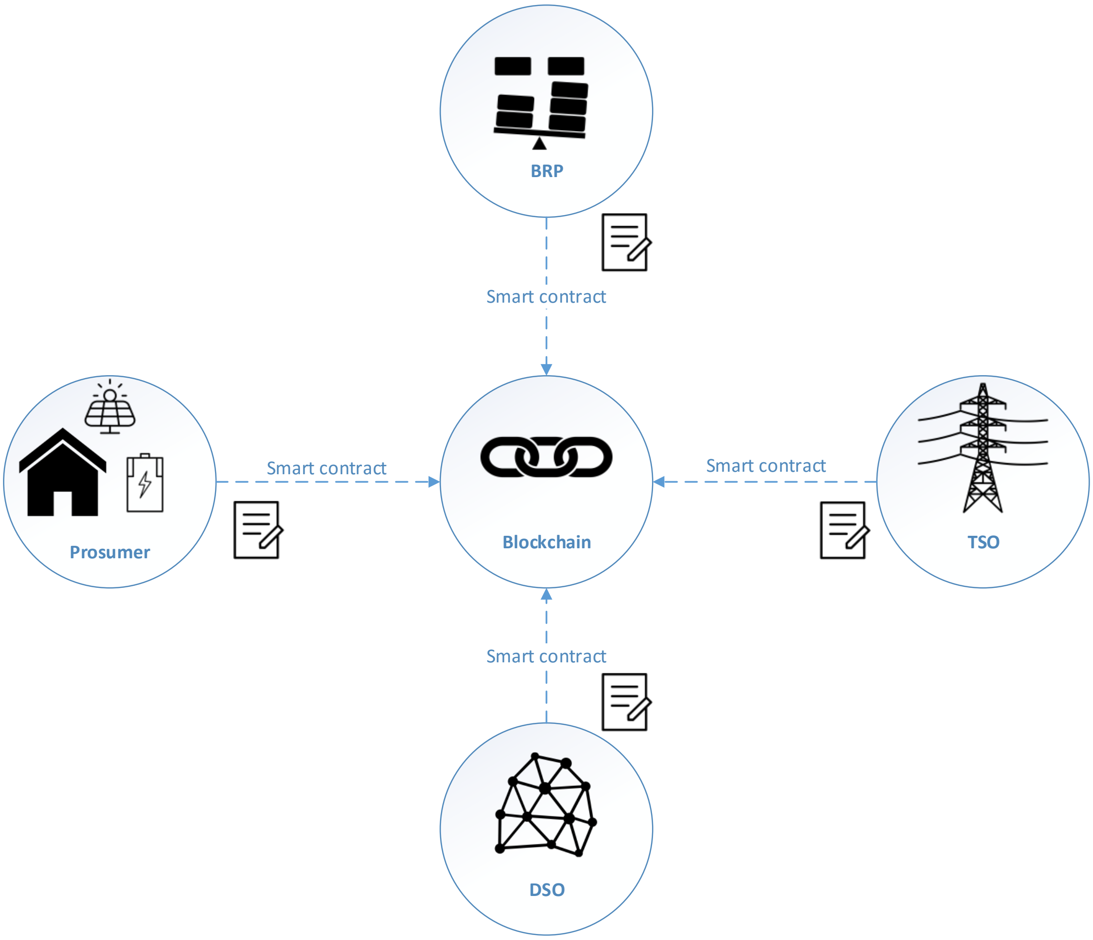

Figure 5-11: Market interaction in flexibility supply by a blockchain application

5.3 Lessons learned from the conceptualisation of the aggregator role and the blockchain application

The goal of this chapter was to provide an answer to the third sub-research question of this research, *How can the aggregator role and a blockchain application be conceptualised in the case of unlocking decentralised flexibility in the Dutch electricity sector?* As observed in this chapter, the aggregator role and a blockchain application are two rather opposing systems with very different design principles in terms of organisation and responsibilities. Conceptualising the aggregator role, it can be posed that the aggregator is a central party fulfilling information management, bundling of services, matching and market clearing, and transaction guaranteeing. The conceptualisation of the aggregator is based on the USEF framework, where the aggregator executes the activities of contracting, planning, validating, operating and settling. The aggregator acts as the central middle-man between prosumers and central markets, where relationships and transactions are formalised with contracts. Blockchain's features of the distributed ledger, smart contract and asset transfer in combination with IoT is able to take over the functionalities of the aggregator role. Due to the decentral characteristics of blockchain, an opportunity arises to trade flexibility outside the boundaries of current market structures. Since the features of blockchain enable automatic matching and market clearing, there is no need to formalise relationships and contracts. Due to possibility of decentralisation and the ability to discard formalisations, it is expected that the performance of a blockchain application is more efficient in terms of operation compared to the aggregator role. It is however still uncertain what challenges arise for both the aggregator role and blockchain application in the system integration within the electricity sector. This chapter provides viable information that is used as input for the detailed analysis of design implications in the chapter 6.

6 Design implications of the system integration of the aggregator and the blockchain application

With input from chapters 3, 4 and 5, this chapter provides an answer to the fourth sub-research question; *What design implications arise from the perspective of system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?* Both internal- and external alignment play an important role in the evaluation and final performance of the aggregator role and the blockchain application. The input for the internal alignment mainly follows from the conceptualisation of the specific aggregation system as elaborated on in chapter 5, whilst the external alignment is based on the insights from describing the design environment chapter 4. Design implications will be identified in a structured manner by following the design knobs from the CD framework. Section 6.1 and 6.2 identify design implications challenging the system integration of the aggregator role and a blockchain application respectively. Section 6.3 provides a comparative analysis of the design implications of the aggregator role and the blockchain application. Finally, section 6.4 provides the bridge of identified design implications towards the future system integration design of the aggregator role and blockchain application in unlocking decentralised flexibility in the Dutch electricity sector.

As stated, the relevant concepts of the electricity sector as found in chapter 4, and the conceptualisation of the aggregator role and blockchain application of chapter 5 serve and as input for the analysis as presented in this chapter. The initial analysis is validated and complemented by means of expert interviews (see appendix 0 for a more detailed elaboration on the method of interviewing in this research). Gained insights from the interviews are used to iterate the initial analysis and are therefore used as an input for identifying factors challenging the system integration of the aggregator role and the blockchain application.

6.1 Design implication of the system integration of the aggregator role

This section elaborates on the design implications of the aggregator role in aggregating decentralised flexibility using the CD framework. Implications in the layers of access, responsibilities and coordination are discussed in 6.1.1, 6.1.2 and 6.1.3 respectively. Implications are identified by reviewing the aspects of the aggregator role along the concepts as described in the engineering (Figure 3-1) - and the institutional (Figure 3-2) perspective on the relevant layer of the CD framework.

6.1.1 Design implications within the access layer challenging the aggregator role

This sub-section elaborates on design implications of the aggregator role structured along the access design knob of the systemic- and institutional environment

6.1.1.1 Lack of standardisation

No large scale flexibility aggregator management application for decentral energy sources is implemented yet. However, concepts of flexibility management are widely researched. In the Netherlands, some use cases around aggregators in the context of demand response, such as PowerMatching City (PowerMatching City, 2017), the Hoog Dalem project (Stedin, 2017d) and the Couperus smart grid (Stedin, 2017a) have evolved over the last couple of years. USEF (2015) opted to standardise market access for the role of the aggregator with the introduction of their framework. However, no specific movement towards the USEF- or some other type of standardisation is currently established. This forms an implication in the design process of the aggregator as potential entrants might have difficulties relating to accessing the market without a sound market standardisation.

6.1.1.2 Central tendency

Deploying the role of the aggregator requires the systemic- and institutional environment to adopt a decentral energy system. At this particular moment, the systemic- and institutional environment and the access design knob are heavily structured in a centralised way and the sector is mainly operated by established parties. Besides, the EU has been working for some years on the development of a European electricity grid. Trends of peer-to-peer activities and the implementation of roles like aggregation ask for a different, more local, bottom-up approach. The sector, established market parties and legislators might face difficulties in adopting this approach since this differs from the traditional views and activities. The concept of the aggregator on the other hand suits very well in the context of the Dutch electricity sector, since it is relatively close to the role of current energy suppliers. Established parties in the sector might find it easier therefore to adopt an aggregator solution over a blockchain application, as they have the ability to exercise some sort of control.

6.1.1.3 Barriers for small parties

Emerging local parties, such as energy cooperation's, might take a role in implementing a flexibility model at a decentralised level. Local and small(-er) parties currently however, experience a barrier to enter the market as it is difficult for them to fulfil the prerequisites of a suppliers license and program responsibility, which are needed for aggregation activities (TenneT, 2017a).

6.1.1.4 Lack of prosumer involvement

Currently, prosumer involvement is still marginal. Consumers are not used to being an active player within the energy system and might not feel the urgency in providing access to their active demand and supply appliances that can provide flexibility.

6.1.1.5 Concerns on privacy and security

Management of information is an important activity to enable aggregator operation. Concerns relating to data privacy and cybersecurity face a lot of attention in society, nowadays. A barrier in involving prosumers is the lack of trust in privacy and security in the aggregator role as it is a data driven application where a single party owns a bulk of consumer data. Data and system security in this case, is within the hands of one single party. Due to a single point of failure it is relatively easy for hackers to gain access to the aggregator data- and operating system.

6.1.1.6 Lack of acceptability

Acceptability of prosumers towards an aggregator systems is questionable. It is uncertain how the perception and attitude of prosumers is towards the interference from a central aggregator in their energy consumption and usage. Acceptability is somewhat related to the possible lacking urgency of prosumers to participate in an aggregator system and the concerns around data privacy and security. The question therefore is whether the aggregator succeeds in activating prosumers in offering their flexibility.

6.1.1.7 Unclear definition of the product of flexibility leads to implications in ownership and operation

Within the current regulatory framework and legislation, activities in the electricity sector are classified either as generation, transmission, distribution, or supply. The potential of flexibility cannot be captured in only one of those activities. Currently, flexibility is usually treated as a generation activity originating from traditional flexibility services such as flexible power plants and pumped hydro storage. Flexibility as defined in this research however, can operate as generation, transmission asset, distribution asset, and load. The single definition on the product of flexibility have some major implications for the operation and ownership of the asset (Anuta et al., 2014; Ruz & Pollitt, 2016).

Despite flexibility's ability to operate as a transmission- and distribution asset and its ability to defer investments in the transmission- and distribution network, access to the flexibility activity is prohibited for network operators. This is because flexibility is currently considered as a generation activity. By adhering to unbundling of the Dutch electricity market, the network operators are not allowed to perform any market distorting activity. With the current definition of flexibility, network operators are therefore not allowed to perform the aggregator role (ACM, 2017b).

6.1.1.8 Decentralisation vs. centralisation

With the introduction of an aggregator, the electricity system seems to become more decentralised and distributed. However, one could question whether initiating an aggregator system would enhance or potentially counteract the decentralisation of the energy system. Unless distributed energy sources are used in the concept of the aggregator, the role will in essence be just another intermediating party operating in the central regime of the electricity sector. Depending on specific responsibilities and coordination, decisions on control strategies and flexibility procurement will mainly be within the hands of the central aggregator.

6.1.2 Design implications within the responsibility layer challenging the aggregator role

This sub-section elaborates on the alignment of the aggregator role structured along the responsibility design knob of technical design principles and economic governance.

6.1.2.1 Difficulty of adoption in current markets,

A future aggregator might have difficulties being adopted by the current electricity market. Currently, demand response loads from the aggregator can only be offered in the balancing market and ancillary services, the wholesale market, and replacement reserves (traded in the intraday market). Other balancing instruments such as primary control, regulating capacity and emergency power do not allow for aggregated loads (SEDC, 2015).

6.1.2.2 Barriers in prosumer related legislation

Some barriers in legislation that relate to the prosumer hamper the deployment of decentralised flexibility. The 'salderings' rule[2] was once initiated to incentivise investment of decentral PV generation. Currently however, it discourages prosumers to invest in flexibility measures such

[2] The 'salderings' rule refers to the stituation where Dutch PV owners can feed in an infinite amount of PV generated electricity tax free in the distribution grid

as storage units and the feed in of PV electricity at the most desired moment (in the absence of congestion). Another legislative barrier is the absence of real-time pricing for end-consumer. Real-time pricing of electricity can incentivise prosumers to adapt their energy consumption as to aid in achieving the most efficient outcomes for the electricity grid (DNV GL et al., 2015; PWC, 2016b).

6.1.2.3 Inability to capture the full value of flexibility services

The value of flexibility from the aggregator is maximised when it can profit from all potential monetary flows. Due to market and regulatory barriers, the full potential of flexibility from the aggregator cannot be monetised. Due to regulatory barriers such as those described in 6.2.2.1 and technical requirements in current electricity markets such as size, availability, stand-by time and forecast accuracy, the aggregator might have difficulties in positioning itself in the market. Since flexibility is considered a generation activity, it is treated as just any other electricity product in the market. Features of flexibility such as quick responsiveness and quality performance can't be monetised in current markets (Anuta et al., 2014; DNV GL et al., 2015; Ruz & Pollitt, 2016). It is therefore very hard to utilise the full potential of revenue from flexibility on a decentralised level, which obviously hampers the business case of the aggregator.

6.1.2.4 Beyond current roles and responsibilities

Following defined responsibilities within the current electricity sector, no responsibilities related to the management of decentralised flexibility exist yet. This could hamper the emergence of the aggregator role. To enable the role of the aggregator it is therefore important for both energy sector parties and legislators to look beyond current roles and responsibilities, markets and system configuration (Fens, 2017; Reineman, 2017; Scheer, 2017; Straathof, 2017; van Gemert, 2017). Roles and responsibilities should be adapted gradually towards this new situation. However coordination and a clear vision are lacking still (Straathof, 2017).

A few possible aggregator roles have been identified by USEF (2015); a combined aggregator-supplier/BRP role, an aggregator as service provider, a delegated aggregator, and an aggregator-DSO/TSO model.

Table 6-1: The possible aggregator models and related implications (partially subtracted from USEF (2015))

Model	**Description**	**Implication**
Combined aggregator-supplier/BRP	Combined role of aggregator and supplier which offers prosumers a supply contract with flexibility. In this way, supply and flexibility can easily be combined.	Profit driven
Aggregator service provider	In this model the aggregator acts purely as flexibility provider to the prosumer and BRPs. The aggregator offers access to other players in the value chain. In this way, flexibility is not sold at the risk of the aggregator.	Need for long-term relationships. Aggregator still needs to comply with balancing responsibility
Delegated aggregator	In this model the aggregator buys flexibility from the prosumer and	Market interactions need to be formalised

	sells it at their own risk to market parties.	
Aggregator -DSO/TSO model	A model in which system operators buy flexibility directly from prosumers	Not allowed by the rule of law since the activity of an aggregator is considered as a form of trade by the Dutch regulator (ACM, 2017b).

The aggregator DSO/TSO model as described by the USEF framework is not possible due to current regulation and liberalisation. The activity of the aggregator needs to be organised in a market environment since the aggregator activity does not contain any characteristics of a natural monopoly. Due to the rising importance of flexibility available on the electricity grid and the possible need to safeguard this activity, it might however be conceivable to view the activity of the aggregator as a public task, as is also the case with the balancing mechanisms on the level of the transmission network (Fens, 2017; Straathof, 2017; van Gemert, 2017). This conflicts however heavily with current regulatory frameworks.

6.1.2.5 Opportunistic behaviour

By organising the activities of the aggregator in a competitive market, opportunistic behaviour can be prevented and price- and cost efficiency can be achieved. It can however be assumed that a competitive aggregator will be profit driven. In this case the best outcomes from the perspective of the distribution grid cannot be guaranteed. Scheer (2017) even argues that having a profit driven competitive aggregator will provoke a commercial play leading to unnecessary peak loads in the distribution grid. An option to overcome undesired profit driven behaviour of the aggregator, is to define the aggregator role in such a way that it needs to comply with specific responsibilities that generate efficient outcomes for the distribution grid.

6.1.3 Design implications within the coordination layer challenging the aggregator role

This section elaborates on design implications in the coordination layer of the aggregator role, technical control mechanisms, and the economic organisation.

6.1.3.1 Techno-operational coordination and the implications

The aggregator system acknowledges a central coordination role for the aggregator. In this role, functionalities of the aggregator as defined by Eid et al. (2015) are; information management, bundling of services, matching and market clearing, and transaction guaranteeing. These functionalities are also reflected in the description of operation regime of the aggregator as developed by USEF (2015); contracting, planning, validating, operating, and settling phase in the operational coordination.

The techno-operational coordination is performed by the aggregator which controls the active load and demand at the level of the prosumer, based on prosumer preferences. A difficulty is the control strategy for the aggregator. Examples of control strategies, manual, incentive-based, predictive-based, transaction-based and override, are provided by USEF (2015), where all strategies are expected to generate different outcomes with respect to the amount of resulting flexibility, the response time, prosumer involvement, and dealing with prosumer preferences. An implication is that there is no clear view on what the most efficient type of techno-operational control strategy is. The specific implications of the control strategies mentioned are presented in Table 6-2.

Table 6-2: Potential control strategies of the aggregator and its related considerations, based on the proposed control strategies as described in USEF (2015)

Strategy	**Description**	**Considerations**
Manual	Prosumer manually controls its loads based on notifications from the aggregator.	Easy and cheap to be implemented in terms of complexity and transaction. Response is however not guaranteed and the flexibility delivered by prosumers will be very limited. Prosumer may behave opportunistic.
Incentive-based	A price signal is sent to the energy management system of the prosumer. Based on the control logic of the appliance, flexibility is provided.	Higher operation costs at the level of the prosumer. Uncertainty about the amount of flexibility available. Prosumer may behave opportunistic.
Predictive-based	The control strategy where the prosumer or the aggregator (or both) generate a forecast on their production and consumption which forecasts the amount of flexibility available	More certainty, but no guarantee on the available amount of flexibility. Rise in operation- and transaction costs. Prosumer may behave opportunistic.
Transaction-based	The strategy where the aggregator and prosumer plan a transaction and where the prosumer is rewarded for delivering flexibility and penalized if not meeting the flexibility plan.	This basically creates responsibility at the level of the prosumer, which has its own e-programme with the aggregator. This control strategy is in need for a transaction contract between aggregator and prosumer. This type of control strategy increases the certainty along the amount of flexibility available and reduces the risk of opportunistic behaviour of the prosumer. There is however a significant increase in interaction complexity between the prosumer and the aggregator.
Override	The control strategy which does not take into account the preferences of individual prosumers. Flexibility is directly managed by the interference of the aggregator.	Certainty on the supply of flexibility. However, the aggregator directly controls the assets of prosumers, which is not desirable from a prosumer perspective.

The control strategies as described in the table above are ways to manage the principal-agent relationship of the aggregator with the prosumer where the aggregator opts to trigger optimal prosumer behaviour. The principal-agent theory clarifies why it is rather complex to ensure optimal individual actor performance in the case of an aggregator system. The problem in the principal-agent relationships is that due to asymmetry in information and the lack of mutual goals, the agent (in this case the prosumer) does not generate the most efficient behaviour for the principal (the aggregator) (Hazeu, 2000). The role of the aggregator provides a mean for the sector policy makers and the parties in need for decentralised flexibility to manage their principal-agent relationship with prosumers. The management of principal-agent relationships can be rather complex though. However, the role of the aggregator allows that these relationships can be actually managed since all defined relationships are formalised.

6.1.3.2 Reflecting on local circumstances

The aggregator model is assumed to provide a decentral solution. The aggregator model, as assumed in this research, is a central oriented model based on the current national wholesale model. In the current USEF model, decentralised flexibility is settled at the national wholesale markets, which establishes a national uniform price on flexibility. The aggregator role is therefore not able to efficiently reflect on local circumstances. For example, when one city in the specific area of a DSO faces problems in the distribution grid (either imbalances or congestion) the electricity price in the national wholesale market is influenced and all areas that have nothing to do with the imbalances or congestion in the congested area face price spikes. In the aggregator model based on the national wholesale market, local desirable or undesirable prosumer behaviour is not rewarded or penalized. This could only be achieved by adopting a market design which can reflect on local circumstances. On the other hand, one could argue that offering decentralised flexibility on the national wholesale model provides the most efficient outcome, since only then the full potential of the product of flexibility can be achieved.

6.1.3.3 Conflicting incentives

The product of flexibility can be deployed in roughly three market services, congestion management for the DSO, portfolio optimisation for BRPs and in balancing markets of TenneT. In coordinating incentives and the flow of electricity it is currently unknown how the aggregator or a blockchain application deals with the conflicting situation where TenneT wants to procure a certain amount of flexibility from a specific area, whereas the DSO in that area would want to prevent congestion with an adverse incentive.

6.1.3.4 The techno-operational coordination

The coordination of the aggregator activities introduce a lot of complexity. The aggregator formalises all its contractual relations to enable for coordination. Contractual relations that need to be established for the functioning of the aggregator are (USEF, 2015) are:

- Flexibility acquisition contract between the aggregator and prosumer, defining flexibility operating conditions and the details of settlement.
- Framework contract between electricity supplier and aggregator for the prosumers services by the aggregator and that specific electricity supplier, including the flexibility operating conditions.
- Flexibility service contract between aggregator and BRP, defining under which conditions the aggregator offers its flexibility to the BRP.
- Revision of connection contract between the DSO with the prosumer
- Long-term flexibility contract between Aggregator and DSO, to ensure flexibility for the DSO.
- Long-term flexibility contract between aggregator and BRP, to procure flexibility in advance.

Cost related to this coordination can be referred to as transaction costs; those costs involved in an economic transaction beyond the costs involved in production. Examples are the costs of drafting, negotiation and the safeguard of agreements, (Hazeu, 2000; Williamson, 1975).

The complexity of coordination is also reflected in the contractual relationships that are formalised to enable the functioning of the aggregator in the market functioning as an intermediary. Williamson (1979) elaborated on transaction costs in intermediary markets, *"I* *am mainly concerned with intermediate-product market transactions."* (p. 234). In principle, transaction costs increase when 1) there is a high degree of specific activities, knowledge or products involved, 2) uncertainty and/or complexity in the market is high and 3) the transaction is recurrent to a high extent (Hazeu, 2000). Costs made by the aggregator in contracting and operating the aggregation service system relating to the concept of transactions costs are:

- The pooling of prosumers
- The contracting of prosumers
- The contracting and collaboration with energy suppliers
- The contracting with BRP's
- Setting up long term relationship with DSO
- Setting up long term relationship with BRP
- Information management in the techno-operational coordination (managing information from a variety of sources, from prosumers to grid operators)
- Negotiating flexibility offering to BRP
- Iterating its flexibility plan according to grid constrains
- Flexibility clearing
- Flexibility settlement

6.2 Design implication of the system integration of the blockchain application

This section elaborates on the design implications of a blockchain application in offering decentralised flexibility. The section is structured along the three alignment knobs of the CD framework; access, responsibility, and coordination in 6.2.1, 6.2.2, and 6.2.3 respectively. Implications are identified by reviewing the aspects of blockchain technology along the concepts as described in the engineering (Figure 3-1)- and the institutional (Figure 3-2) perspective on the relevant layer of the CD framework.

6.2.1 Design implications within the access layer challenging the blockchain application

A blockchain aggregation system is rather disruptive considering the systemic- and institutional environment in the access design knob by distributing power and operation to a decentralised level. Blockchain technology is a disruptive technology, redefining the way one might think about organising transactions within the electricity sector, both from a technical and institutional perspective.

6.2.1.1 Technology issues and lack of standardisation

Expectations are that blockchain can play a major role in the energy sector (C. Burger et al., 2016). Despite some blockchain energy experiments and pilots developing, no functional large scale blockchain applications exist in the energy sector yet. Besides, a need for the technology itself to be improved before implementation in a system such as an aggregation system, is likely. Currently, technical issues with blockchain technology are scalability (the Bitcoin blockchain for example is limited to 7 transactions per second), slow processing speed, security issues and the significant use of electricity (Swan, 2015). Since the technology has only just started maturing, much needed standardisation within the technology is currently lacking.

6.2.1.2 Central tendency

Currently, the sector is characterised by a central configuration and management. Just as for the aggregator role, the central tendency of the current systemic- and institutional environment is problematic. Deploying a blockchain application will ask the systemic- and institutional environment to adopt a decentral energy system, which is at odds with the current sector. Implementation of a blockchain application unlocking decentralised flexibility asks for a different approach due its rather redefining way of organisation. The sector, established market parties and legislators might face difficulties in adopting this approach since this differs from traditional views and activities.

6.2.1.3 Barriers for small parties

Emerging local parties, such as energy cooperation's, might take a role in implementing a flexibility model at a decentralised level Local and small(-er) parties currently however, experience a barrier to enter the market as it is difficult for them to fulfil the prerequisites of a suppliers license and program responsibility, which are needed for aggregation activities (TenneT, 2017a).

6.2.1.4 Lack of prosumer involvement

Currently, prosumer involvement is still marginal. Consumers are not used to being an active player within the energy system and might not feel the urgency in providing access to their active demand and supply appliances that can provide flexibility.

6.2.1.5 Lack of acceptability

Acceptability of prosumers towards a blockchain based aggregation system is questionable. It is uncertain how the perception and attitude of prosumers is towards the relatively unknown technology behind blockchain. Blockchain is at odds with the organisation of transactions as we have known them for years using a central point of management. Issues such as privacy and security are also handled in a different way compared to what society is used to, and might therefore form a barrier for acceptability

6.2.1.6 Opposing current parties and business models

Institutionally, the application of blockchain implies a radical change. The institutional transaction is executed by an automated process and trust is put in the blockchain's features of cryptography and immutability. In traditional transaction systems, trust is placed in a central trusted third party. Implementation of a blockchain application is therefore at odds with market structures and business models of existing processes and businesses. A blockchain implementation can ultimately hamper current market structures and business models and therefore threat the role of current established parties. Scheer (2017) even argues that traditional players will try to oppose the implementation of a blockchain activity since it can hamper their current activities.

6.2.1.7 Unclear definition of the product of flexibility leads to implications in ownership and operation

Within the current regulatory framework and legislation, activities in the electricity sector are classified either as generation, transmission, distribution, or supply. The potential of flexibility cannot be captured in only one of those activities. Currently, flexibility is usually treated as a generation activity originating from traditional flexibility services such as flexible power plants and pumped hydro storage. Flexibility as defined in this research however, can operate as generation, transmission asset, distribution asset, and load. This have some major implications for the operation and ownership of the asset (Anuta et al., 2014; Ruz & Pollitt, 2016).

Despite flexibility's ability to operate as a transmission- and distribution asset and its ability to defer investments in the transmission- and distribution network, access to the flexibility activity is prohibited for network operators. This is because flexibility is currently considered as a generation activity. By adhering to unbundling of the Dutch electricity market, the network operators are not allowed to perform any market distorting activity. With the current definition of flexibility, network operators are therefore not allowed to adopt a blockchain application which unlocks decentralised flexibility (ACM, 2017b).

6.2.1.8 Inability to capture the full value of flexibility services in a blockchain application

The value of flexibility from the aggregator is maximised when it can access all potential value streams (already discussed in 6.1.2.3). Due to market and regulatory barriers, the full potential of flexibility from the aggregator cannot be monetised. It is therefore very hard to utilise the full potential of revenue of flexibility from a decentralised level which obviously hampers the business case of deploying a blockchain application.

6.2.2 Design implications within the responsibility layer challenging the blockchain application

This section elaborates on the implications and considerations of responsibilities in a blockchain application structured along technical design principles and economic governance.

6.2.2.1 Adoption in current markets

For the blockchain application, the question rises how the product flexibility is offered in the market. Blockchain has the ability to act as a virtual power plant, but can also offer flexibility using micro-transactions in the market, e.g. where each flexibility portfolio of a prosumer is sold individually in the market. Both options face implications. By offering flexibility by means of a virtual power plant, the flexibility products are aggregated and the same implications as for the aggregator role arise. Currently, demand response load from the aggregator can only be offered in the balancing market and ancillary services, the wholesale market, and replacement reserves (traded in the intraday market). Other balancing instruments such as primary control, regulating capacity and emergency power do not allow aggregated loads (SEDC, 2015).

In offering the product of flexibility by the use of micro-transactions, the difficulty of minimum technical requirements for ancillary services arises (Anuta et al., 2014; Ruz & Pollitt, 2016). Besides, current markets have difficulties in the appreciation of the flexibility product (DNV GL et al., 2015; Ruz & Pollitt, 2016) and meet the requirement of providing an infinite output of energy (Anuta et al., 2014; DNV GL et al., 2015). Finally, current market structures in the Netherlands, such as the salderings rule and the lack of real-time pricing, block the incentive for prosumers to invest in flexibility providing equipment (DNV GL et al., 2015; PWC, 2016b).

6.2.2.2 Barriers in prosumer related legislation

Some barriers in legislation that relate to the prosumer are present. The salderings rule was once initiated to incentivise investment of decentral PV generation. It however discourages prosumers to invest in flexibility measures such as storage units and the feed in of PV energy at the most desired moment in time. Another legislative barrier is the absence of real-time pricing. Real-time pricing of electricity can incentivise prosumers to adapt their energy consumption that generate the most efficient outcomes for the electricity grid (DNV GL et al., 2015; PWC, 2016b).

6.2.2.3 Beyond current roles and responsibilities

Following the responsibilities within the current electricity sector, no responsibilities relating to the management of decentralised flexibility exist yet. In realising a blockchain application it is important for both energy sector parties and legislators to look beyond current roles and responsibilities, markets and system configuration (Fens, 2017; Reineman, 2017; Scheer, 2017; Straathof, 2017; van Gemert, 2017). Roles and responsibilities should be adapted gradually to this new situation. However, coordination and a clear vision are lacking still (Straathof, 2017).

6.2.2.4 Issues within the network configuration of a blockchain application

As discussed in 5.2.4, three possible configurations exist in the typology of a blockchain; public permissionless blockchains, public permissioned blockchains, and private permissioned blockchains. The question is whether public permissionless blockchains are suitable for the specific case of unlocking decentralised flexibility. The current public permissionless blockchains are mainly focussed on peer to peer transactions outside the scope of current markets, such as Bitcoin, Ethereum, or the Brooklyn microgrid and Oneup POWR in the energy use cases. In the use case of unlocking decentralised flexibility transaction are peer-to-market and need to take into account current market structures. A major implication of public blockchains is that because of full decentralisation, it is hard to implement steering and regulation mechanisms. According to Hijgenaar (2017), there is a need for some sort of responsible actor in charge of the blockchain, considering the criticality of the electricity infrastructure by means of a trusted party.

The issue of the ability of assigning responsibilities, and the control and monitoring of the performance within a blockchain application, is relevant to both a public- and private blockchain. Within a private blockchain however, it is easier to impose responsibilities, by issuing a trusted party. In this situation, the trusted party is prone to specific rules imposed by legislators that need to be complied with in the blockchain operation. Within the current regulatory framework there is only room for issuing the trusted party role to a market entity. According to Scheer (2017), strict regulation of a blockchain is also not necessary as long as the rules of the game are defined in a sufficient way. In this case, rules in the blockchain should opt to safeguard the flexibility model from opportunistic behaviour.

6.2.2.5 Blockchain roles and responsibilities

Choosing a private blockchain, somewhat opposes the decentralisation and disintermediation ability of the blockchain. Both the development, validation and operation of the blockchain is performed on a central level. The added value of such a system over an aggregator is therefore questionable. Originally blockchain opts to place trust of the system in cryptographic proof and allows for transactions without a trusted central party. However, in choosing a blockchain with some sort of permission, the blockchain is in need for trusted parties (Hileman & Rauchs, 2017). Many roles need to be assigned by setting up and operating a private blockchain. Hileman and Rauchs (2017) for example mention the roles of access control, permission management, gatekeeper for terms and conditions, software maintenance and updates, dispute resolution and arbitration and settings terms for asset issuance.

In a blockchain utopia, the blockchain application is governed by the end-users themselves. Reflecting this to the role of smart contracts in a blockchain application unlocking decentralised flexibility, prosumers would have to personally define their preferences in smart contracts. Due to a lack of knowledge on both the set-up of smart contracts and electricity markets, and the expected desire of prosumers to have an easy-to-use application there is a need for some sort of trading agent/platform. This trading agent can form the trade linkage between the prosumer and a blockchain application (Eid, 2017; Reineman, 2017; Rutten, 2017). Again, this will lead to some sort of centralisation, which opposes the decentralisation and disintermediation of a blockchain application.

6.2.2.6 Decentralisation vs. centralisation in a blockchain application

The discussion shows strong contradictions between decentralisation and centralisation are present. Where on the one hand the implementation of a blockchain application invokes the shift towards decentralising the energy system by enabling decentralised flexibility sources, the entry of the prosumer to enter electricity markets and decentral operation of this system on the other hand some disadvantages from the decentralised structure of public blockchains will arise. To solve for this, some centralisation such as choosing for a private blockchain, incorporation of a trusted party that operates the blockchain subject to rules and regulation, and the need for a trading agent that can facilitate access of prosumers to the blockchain via smart contracts, might be necessary. Despite the fact that blockchain is perceived as an application which enables decentralising and disintermediation of the electricity market, the discussion points out that there is still a need for central steering in a critical infrastructure such as the flexibility market in the electricity sector, which is rather contradictory.

6.2.2.7 Principal-agent relationships in a blockchain application

In the aggregator model, the complexity relating to principal-agent relationships is to manage the formalised relations which originate from the implementation of an aggregator. In the blockchain application the complexity, in the principal-agent relationships is that they are not formalised and therefore hard to manage.

6.2.3 Design implications within the coordination layer challenging the blockchain application

Whereas the techno-operational coordination and the economic organisation of the aggregator is coordinated in a central manner, the coordination of a blockchain is decentralised (even when organised in a private blockchain) by using the smart contract feature of blockchain implementations such as available in the Ethereum blockchain, R3 or Hyperledger Fabric. This section will elaborate on the coordination of unlocking decentralised flexibility using blockchain, and how this challenges design by considering the system integration perspective.

6.2.3.1 Price incentives and local markets in a blockchain application

A blockchain application eminently provides an opportunity to create local markets for flexibility, since blockchain provides the opportunity of automatic settlement. In this case, no intermediation of the national wholesale market is necessary. It is however unsure how the right price for flexibility is established in such a market. Besides, a linkage with the national wholesale market might be useful to utilise the full potential of the flexibility product. Doing this opposes the potential of blockchain to interact outside the scope of central markets.

6.2.3.2 Conflicting incentives

An implication in coordination, relevant to both systems, is the possibility of conflicting signals when the product of flexibility is deployed in three potential market services; congestion management for the DSO, portfolio optimisation for BRPs and in balancing markets of TenneT (de Joode, 2017). It is currently uncertain how the blockchain application should deal with the conflicting situation in which TenneT would want to procure a certain amount of flexibility from a specific area, whereas the DSO in that area would want to prevent congestion with an adverse incentive.

6.2.3.3 Scalability and consensus issues

As discussed, the current blockchain processing speed and capacity is rather low due to the protocol of the leading consensus mechanism of proof-of-work. The processing speed of blockchain currently complicates scalability and the step-up to real-time networks. Using smart contracts and real-time matching of flexibility demand in supply, the blockchain network is in need for fast processing speed. Private blockchains have some major advantages on the processing speed since transactions do not need to be validated by the entire network but only by a priori selected nodes. It remains uncertain whether the blockchain is fast enough to manage a flexibility model on a real-time basis.

Another flaw of the proof-of-work consensus method is the energy consumption related to the transaction. Energy consumption contributes to the transaction costs of an individual transaction. The Bitcoin network for example uses over 20 TWh a year which is similar to the total power consumption of Ecuador (Choi, 2017). Whereas currently proof-of-work is the leading consensus method, Ethereum is looking into implementing a proof-of-stake consensus mechanisms (Choi, 2017; coindesk, 2017). The proof-of-stake consensus method reduces the energy consumption for the validation of transactions, ultimately lowering transaction costs. A final implication of proof-of-work is related to the majority rule within the block validation. Since an amount of 51% of the blockchain users will represent the truth within a blockchain, so-called 51% attacks are possible. In this case malicious nodes can influence the outcomes of the blockchain (Hileman & Rauchs, 2017).

6.2.3.4 Difficulty of coupling of the physical product of flexibility with the transactional system of the blockchain

An issue of a blockchain application is the linkage of the physical product of flexibility with the transactional system of a blockchain application (van Gemert, 2017). Imagine a transaction between a prosumer and a BRP in which the BRP procures a certain amount of flexibility from a prosumer to optimise its e-programme. The smart meter of the prosumer monitored 10 kWh of electricity fed in by the prosumer and registers this into the blockchain. The question then is, how it can be monitored in which way the procured power actually arrives at the BRP. In blockchain, the transaction between both parties is recorded. However, the physical reality does not have to match per se. A blockchain application is not able to assess whether the given input, the amount of flexibility in this case, is correct. This refers to the principle of GIGO, garbage in, garbage out. To deal with this implication a trusted party is needed to verify whether the input in the blockchain is correct or not (Hileman & Rauchs, 2017).

6.2.3.5 Smart contract as control mechanism

A smart contract enables the ability to include automation in blockchain operation, and is considered a boundary condition for enabling the settlement of real-time transactions. By running a smart contract on the blockchain, contracts can be established based on pre-defined settings. The smart contract uses pre-defined settings to decide whether a specific transaction should be executed (Swan, 2015). Based on pre-defined settings (e.g. a price- or capacity threshold for transactions) from both the side of the prosumer and a purchaser of flexibility, a transaction can be established. Coupling the smart contract to an IoT device triggers the flexibility unit to be activated to supply, withdraw or postpone the demand for electricity from the grid to offer flexibility. The smart contracting application on the blockchain in combination with IoT thus offers an alternative to the operation phases, contracting, planning, validating, operating and settlement, as defined in the aggregator model by (USEF, 2015). In this model the smart contract is defined on the blockchain, the planning and validation of information (obtained from the DSO and parties that are planning a flexibility transaction) need to be updated continuously on the blockchain to have the correct information available to execute the smart contract. Finally, the executed smart contract need to be established on the blockchain ledger to execute the settlement of performed transactions. Due to the current issues of processing speed, it is uncertain whether the combination of smart contracts and IoT can actually foresee in the real-time management of a flexibility model on a large scale.

The major advantage of using a blockchain in the execution of transactions is its potential efficiency in terms of transaction costs. Davidson et al. (2016), MacDonald et al. (2016), Bheemaiah (2017) and many others mention that a trusted blockchain ledger lowers transaction costs and therefore causes economic efficiency gains, relative to a situation with some sort of market intermediary. Considering relational contracting theory (Williamson, 1979, 1985), smart contracting allows for automated classical contracting in a market governance without high costs for the flexibility purchasing party for searching-, negotiating- and settlement of the contract. Using smart contract functionality, pre-defined contracts can be executed automatically without the need of market intervention, long-term relationships, high efforts in negotiation or complex settlement systems. The smart contract basically forms a legal framework in which the automatic execution of transactions takes place. Literature reviewing the transaction costs of a blockchain application however, consider the complete disintermediation. As discussed, the complete disintermediation within the case of unlocking decentralised flexibility by use of a blockchain implication is rather impossible. The efficiency gains in terms of transaction costs might therefore be lower than assumed at first sight.

6.3 Overview of implications of the aggregator role and blockchain application

The aggregator role is a classic way of organising a transaction, by placing an intermediary in between the two parties performing a transaction. In a blockchain application this role is replaced by rules of code without the need of central coordination. It is hard to make this radical shift to a blockchain based system coming from a centrally managed systems such as the electricity sector. In comparing the systems, they both have their advantages and disadvantages. Where the aggregator is a central party which can be prone to regulation, blockchain is a decentralised system that is harder to regulate. Where the aggregator coordinates a flexibility model by centrally managed contracts invoking a lot of complexity, interaction, and transaction costs, the blockchain coordinates this in a decentralised way making use of decentralised automated smart contracts, reducing complexity in terms of interaction and transactions. The main considerations in comparing both systems is therefore centralised control and complexity versus decentralised self-regulation and efficiency. Specific characteristics of the aggregation systems heavily influence design implications which affect the system integration ability of an aggregation system. Table 6-3: Overview of factors challenging the system integration of the aggregator role and blockchain application in unlocking decentralised flexibility, provides an overview of different design implications as identified in the analysis of section 6.1 and 6.2

Table 6-3: Overview of factors challenging the system integration of the aggregator role and blockchain application in unlocking decentralised flexibility

	Aggregator	**Blockchain**
Access	Lack of standardisation forms barrier to potential entrants Central tendency of current systemic- and institutional environment Barriers for small local parties in operating on the electricity market Lack of prosumer involvement Concerns of security and privacy in data storage. Single point of failure in managing security and privacy Lack of acceptability by prosumers Decentral assets are managed by a central party Incomplete definition of flexibility influences possibilities of operation and ownership of the asset Lack of experimental room for network operators due to unbundling	Lack of standardisation forms barrier to potential entrants Technical issues of processing speed, security and energy consumption Central tendency of current systemic- and institutional environment Barriers for small local parties in operating on the electricity market Lack of prosumer involvement Lack of acceptability by prosumers to use blockchain application Concern of data privacy and security Lack of acceptability of current market parties because disintermediation threatens current businesses and market structures Incomplete definition of flexibility influences possibilities of operation and ownership of the asset Lack of experimental room for network operators due to unbundling
Responsibilities	Barriers in current balancing mechanisms; Aggregated load is not allowed in most balancing market mechanisms Barriers in current market structures such as saldering and lack of real-time pricing Inability to capture the full value of flexibility services in a blockchain application Aggregator role is an activity beyond current roles and responsibilities Aggregator role is not allowed by network operators A competitive aggregator may behave in an opportunistic way	Barriers in current balancing mechanisms; Aggregated load is not allowed in most balancing market mechanisms Offering flexibility in micro-transactions faces the barrier of minimum technical requirements in electricity markets Market structures such as saldering and lack of real-time pricing discourage the investment in decentral flexibility applications Inability to capture the full value of flexibility services in a blockchain application Activity of flexibility model in a blockchain application role is an activity beyond current roles and responsibilities

	Relationships in the aggregator model are all formalised. Complexity in managing these principal-agent relationships. Relatively easy to assign specific responsibilities and to control and monitor the performance due to central organisation	Public blockchain will not suffice when implemented in a critical infrastructure It is rather hard to implement steering and regulation mechanisms in a blockchain application Controlling and monitoring is a major issue in a blockchain application Private blockchain keeps the need for trusted parties Many roles needed in development and operation of a private blockchain network Need for trading agents that act on behalf of prosumers Principal-agent relationships are hard to manage since relationships are not formalised
Coordination	Unclear what control strategies are the most efficient in terms of availability of flexibility, prosumer involvement and price incentives Hard to coordinate the principal-agent relationship of the prosumer and aggregator Aggregator model is not able to efficiently reflect on local circumstances Serving flexibility in multiple markets can generate conflicting incentives Many complexities regarding to the central coordination by the aggregator system due to the presence of contracts and many interactions in coordination phases: contracting, planning, validating, operating and settling. Coordination is quite complex inducing significant transaction costs	Blockchain provides the ability to go into local markets outside current central markets. It is uncertain how the price of flexibility will evolve in such a market. Full potential of flexibility is provided when serving in all possible markets. Serving flexibility in multiple markets can generate conflicting incentives Scalability- and speed issues challenge the ability for real-time management of a flexibility model Current leading consensus mechanism, proof-of-work, is very energy intensive Current leading consensus mechanism, proof-of-work, is prone to 51% attacks. Very hard to link the physical product of flexibility to the transactional system within the blockchain Garbage in is garbage out. Need to be sure that the input on the blockchain is 100% correct Automated decentralised coordination significantly lowers transaction costs. But, transaction cost might not be as low as expected.

As can be concluded from Table 6-3, the external alignment proves to be an implication for both aggregation systems. Because of the radical character of blockchain technology, it is expected that more implications arise on the dimensions of accessibility and technology issues, and the fit with the current systemic- and institutional environment compared to the aggregator. In blockchain applications, trust is placed within technological principles of blockchain technology, whereas in the aggregator role trust is placed in the central aggregator organisation. Within the role of the aggregator, responsibilities are easy to be assigned to because of this central point of organisation. Implications in the aggregator role relate to the assignment of the right rules and regulations, which safeguard the sector and prosumers against undesirable behaviour of the aggregator. Disintermediation and self-organisation by a blockchain application reduces complexity and increased efficiency in terms of coordination compared to an aggregator. In terms of responsibilities, blockchain will have difficulties in assigning those specific roles and responsibilities. It is however expected that a blockchain that unlocks decentralised flexibility should be organised in a private network typology that enables some sort of steering- and safeguard mechanism. Other roles in a private blockchain application in the case of unlocking decentralised flexibility are trading agents that link the prosumer with the blockchain and several roles relating to blockchain operation. In this case it is therefore hard to achieve the full potential of disintermediation and self-organisation. Reflecting both systems on its alignment with the current design principles as defined in the layer of responsibilities, many implications arise. Both the aggregator role and a blockchain application face difficulties to be adopted by current market structures because of the prohibition of aggregated loads, minimum technical requirements of electricity markets, uncertainty on the full monetisation of flexibility, the presence of the 'salderings' rule and the lack of real-time pricing.

Because of the use of smart contracts within the opted blockchain application, blockchain enables trading flexibility outside current markets to better reflect on local circumstances and allow for direct trade without intermediation of central markets. However, the product of flexibility is offered at its most efficient when offered to all markets it can possibly serve. Connection of the blockchain application with national wholesale markets may therefore not be discarded. Serving three different market services, the question remains how both models deal with conflicting incentives from different markets.

In terms of coordination efficiency, the blockchain application shows to be more efficient. This is mainly due to automatic coordination by means of smart contracts and IoT and the absence of formalised relationships, which have a positive impact on the transaction costs. Implications of the blockchain application in terms of coordination, are the difficulty to couple the physical product of flexibility with the transaction system of the blockchain and issues regarding to scalability and current consensus mechanisms. Besides, the efficiency gain in coordination might not be as big as expected, since the analysis pointed out that there is a need for some sort of centralisation via a trusted party and trading agents. Implications for the aggregator role are related to the central coordination, related transaction costs, and complexities that arise in efficiently coordinate prosumers in terms of flexibility supply.

6.4 Overcoming design implications – Towards the detailed design of aggregation systems

After the identification of design implications in 6.1 and 6.2, and the overview of these implications in 6.3, the question arises how these design implications specifically challenge the system integration of the aggregator role and blockchain application in unlocking decentralised flexibility. This section zooms in on how specific design implications can be classified in linking them to the future detailed design of both the aggregator role and a blockchain application. In the previous section, the analysis of design implications was continuously structured along the principles of the CD framework. This however provides no insight in the prioritisation of design implications. In this section, the design implications, as identified in the previous section of this chapter, have been classified in three groups; design implications specific to both aggregation systems (6.4.1), design implications that need to be removed or improved (6.4.2), and design implications that need to be decided on in future design (6.4.3). The first group of design implications basically give insight in the specific differences among several performance indicators for the aggregator role and blockchain application. The second group gives insight in changes needed for the implementation of a model for flexibility at a decentralised level. Finally, the third group gives insight in future choices that need to be made when the aggregator role of blockchain application is designed in more detail.

Note that this section only comprises out of the classification of design implications as identified in this research. Other obvious design implications such as implementation costs, and business models are outside the scope.

6.4.1 Performance considerations of the aggregator role or blockchain application

This sub-section elaborates on the performance which emerges from the identified design implication that needs to be considered in comparing the aggregator role and blockchain application in unlocking flexibility at a decentralised level. Mapping the considerations for either one of the aggregation systems is based on the design implications, as found in the CD framework. Insights from Table 6-4 can be used to make the considerations between the aggregator role and blockchain application more explicit. Ultimately, the individual preferences of specific stakeholders are decisive in deciding which aggregation system generates the most desired outcomes in terms of performance.

Table 6-4: Performance indicators of the aggregator and blockchain application

	Aggregator	**Blockchain**
Fit with current environment	At odds with current sector because of decentral sources, but the role of the aggregator fits within current business models due to the centralisation of organisation	At odds with current sector and activities of established parties due to the use of decentral sources and disintermediation of organisation
Technical complexity	Technically relatively mature. Many use cases, much written on in literature.	Technically very immature. Few use cases, technology is emerging and complex.
Governance	Central organisation that manages the linkage between prosumers and central markets	Technology automatically manages the linkage between prosumers and central markets.
Regulating ability	Because of central organisation, relatively easy to regulate and implement steering- and safeguard mechanisms	Due to disintermediation it is uncertain how the organisation of flexibility activity within the blockchain can be regulated

Coordination complexity	Formalised relationships with a lot of complexity and interaction	No need for formalisation of relationships due to the usage of smart contracts
Transaction costs	Significant transaction costs due to complexity	Relatively low transaction costs due to efficient coordination

6.4.2 Design implications that need to be removed or improved

Design implications found in this category are those that need to be removed or significantly improved in order to enable successful system integration of the aggregator role and blockchain application. The removal or significant improvement of design implications, as listed in Table 6-5, can be considered as boundary conditions for the implementation of both aggregation systems. Design implication that need to be removed or improved are basically barriers, as found in a variety of segments in the electricity sector. Without the significant improvement of these barriers, it is expected that the system integration it is very complicated.

Table 6-5: design implications that need to be removed or improved

Type of barrier	Design implication	Rationale
Technical	*Lack of standardisation*	Without substantive standardisation and use cases the development is lagging and assessment of economic and technical effects is lacking
Regulatory	*Revision of current roles and responsibilities*	Players in the electricity sector need to adopt new activities and roles and responsibilities which are related to a flexibility model at a decentralised level
	Central tendency	With the development of a decentralised flexibility model, it is necessary to revise the current regulatory frameworks and legislations which are currently optimised for a central configuration
	Unclear definition of flexibility	Due to the absence of a clear definition of the product of flexibility, it is now treated as generation hampering possibilities in operation in electricity markets and potential forms of ownership of assets
	Lack of prosumer involvement	Necessary for the success of both aggregation system is the degree of prosumer involvement. Mainly dependent on incentives and the removal of discouragement in current regulatory frameworks such as saldering and the lack of real-time pricing

Market	*Barriers in electricity markets*	Current electricity markets have difficulties in adopting aggregated flexibility products. Prohibition of aggregated loads, minimum technical requirements, the inability to currently form a barrier for the operation of aggregation systems within current electricity markets
	Inability to fully monetise the product of flexibility	The responsive character and quality of flexibility in output is currently not rewarded. The full potential of the product of flexibility can therefore not be monetised

6.4.3 Further specification of design variables

Depending upon the choice for the aggregator or a blockchain application in the fulfilment of a flexibility model at a decentralised level, the system integrative design should focus on specific design variables after the boundary conditions, as specified in 6.4.2, are fulfilled. Table 6-6 provides a listing of detailed design variables that need to be designed for. The purpose of this listing is to gain insight in design variables that need more comprehensive specification in the phase of detailed design of both aggregation systems. Take into account that the design variables as identified in Table 6-6 and are only a preliminary listing of design variables specified in the analysis of design implications in this research and therefore far from complete.

Table 6-6: Design variables for the aggregator role and blockchain application that need further specification

Aggregator	**Blockchain application**
Specific roles and responsibilities	Specific roles and responsibilities
Specific rules and regulation	Specific rules and regulation
Aggregator control strategies	Specific design of blockchain platform
Aggregator incentive strategies	Blockchain control strategies
Safeguard of data privacy and security	Specific network typology
	Safeguard of data privacy and security

6.5 Lessons learned from the analysis of design implications for the aggregator role and blockchain application

The purpose of this chapter was to provide an answer to the fourth sub-research question; *What design implications arise from the perspective of system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?* As can be drawn from this chapter, many implications on a variety of perspectives arise by analysing the system integration of the aggregator role and blockchain application. In this research, design implications have been structured in the layers as conceptualised by the CD framework; access, responsibilities and coordination. This section elaborates on the most important lessons learned from the analysis in this chapter.

In the layer of access, it is expected that both aggregation systems have difficulties to be adopted by the current central focussed perspective and legislation- and regulatory frameworks of the electricity sector. This effect is expected to be bigger in the case of a blockchain application, since blockchain is a radical innovation that threatens current market structures and business models. Besides, the technical complexity of a blockchain is way bigger since the technology only just started to emerge.

In the layer of responsibility, different implications arise for both aggregation systems. In an aggregator system, rules and responsibilities can be assigned to the aggregator as a central party. The question in adopting the aggregator role is therefore how these rules need to be designed. By implementing a blockchain application, a system in which governance is not maintained by a central party, the question is how to assign these specific rules and responsibilities. At first it was assumed that blockchain could enable for a disintermediated system. However, the need for a private blockchain operated by a trusted party, and the need for many roles in blockchain operation, opposes the disintermediation ability of a (public) blockchain.

In the layer of coordination, the blockchain application seem to be less complex to coordinate due to the automation of coordination processes. Within the aggregator model, relationships between prosumers and flexibility demanding parties have been formalised with the interference of the aggregator. Coordination in the aggregator model is therefore rather complex, inducing significant interaction and transaction costs.

Design implications as identified in this chapter have been classified in three categories, design implications that define the considerations of both aggregation systems on different performance indicators, design implications that need to be resolved to enable the successful implementation of a flexibility model at a decentralised level, and design implications that need to be further elaborated on in the detailed design of both aggregation systems.

7 Discussion and reflection of the research

This chapter elaborates on the discussion of the research results in section 7.1 and the reflection on the relevance and quality of this research in section 7.2.

7.1 Discussion

The discussion section elaborates on practical issues and other points of discussion for implementing an aggregation system in offering decentralised flexibility. It also presents suggestions for future research. 7.1.1 discusses the difficulty of changing informal institutions, 7.1.2 discusses the inability for self-organisation and disintermediation of blockchain in unlocking decentralised flexibility, 7.1.3 discusses the possibility of a hybrid aggregator-blockchain model, 7.1.4 discusses the uncertainties around market size of a flexibility model, 7.1.5 nuances the hype around blockchain technology, and finally 7.1.6 provides suggestions for future research.

7.1.1 Difficulty of changing informal institutions

Regardless of the choice for one of the aggregation systems, there is a need for significant perception changes to enable system integration. Whereas the current sector is mainly focussed on a central way of organisation, markets, and coordination, the aggregation systems unlocking decentralised flexibility are in need for a more decentral approach. This is also elaborated on in the analysis referring to the boundary conditions for successful implementation of both aggregation systems in 6.4.2. These boundary conditions are currently mainly hampered by design implications as found in the informal institutions in the access layer of the CD framework. Informal institutions are now prone to a heavy centralised view on the electricity sector by legislators, regulators and established sector players. As indicated in Scholten and Künneke (2016) the layer of access only tends to change very slow. Change in this layer however, is indispensable in triggering a decentral approach in the electricity sector, which is necessary for the implementation of a aggregation system. The current technological developments and the need for decentralisation however, could be major influencers for a change in the informal institutions. Besides, active steering from governmental organisations such as the Ministry of Economic Affairs can be seen as a mean in guiding the change in the informal institutions by stipulating the need for decentralisation. The change in the informal situations can open up the opportunity for established parties and governmental organisations to think pro-actively of energy systems beyond the current roles, responsibilities, regulation and legislation. The creation of a decentral design environment and to break the current lock-in in current centrally focussed energy systems.

7.1.2 Inability for self-organisation and disintermediation

The aggregator role and a blockchain application are two opposing systems. Due to the specific governance features of blockchain application it was assumed that a blockchain application enables the self-organisation and disintermediation in deploying a model for decentralised flexibility. An assumption in this research was that both aggregation systems could be perceived as organisational substitutes. This assumption only holds when the blockchain application could actually deliver in the full self-organisation and disintermediation of the flexibility system. Gained insights from the analysis and the expert interviewing pointed out that the self-organisation and disintermediation effect of a blockchain application in facilitating the deployment of decentralised flexibility might not be considered as likely in the specific case of unlocking decentralised flexibility. The need for a private blockchain, having a trusted party and several roles in the operation of the blockchain all are some sort of centralisation. Besides, to fully utilise the potential of decentralised flexibility in terms of supply and demand, there is a need to link the product of flexibility to the national wholesale market so decentralised flexibility can provide all potential market services; congestion management prevention for the DSO, portfolio optimisation for BRPs and balancing mechanisms for TenneT. From this research it can therefore be concluded that blockchain is unable to achieve the potential of disintermediation and self-organisation in unlocking decentralised flexibility.

7.1.3 Hybrid model

As 7.1.2 discusses, blockchain is unable to utilise the full potential of disintermediation and self-organisation. Whereas at first it was assumed that blockchain technology could be considered as an organisational design, making the aggregator role obsolete, the discussion above argues that blockchain technology and the aggregator role do not differ that much in terms of organisation. Often discussed in the interviews was the possibility of a hybrid model in which blockchain merely operates as the coordination mechanisms of the aggregator role.

In analysing both systems, the aggregator role shows to be able to have a better alignment in the responsibility layer, whereas blockchain outperforms the aggregator in the coordination layer (mainly in terms of transaction costs). In a hybrid model, all rules, responsibilities and safeguards relevant to an aggregation system can be assigned to the aggregator role whilst blockchain technology only acts as the operational mechanism of the aggregator organisation to gain efficiency in terms of aggregator operation. An example of this could be the situation in which an aggregator initiates a private blockchain and provides a platform on which it uses all sorts of data on flexibility demand and supply, to automate the operation and settlement of transactions on the blockchain. Blockchain being the operational model of the aggregator allows the aggregator to abandon the heavy formalised character of contractual agreements, as described in the USEF framework, lowering transaction costs and gaining efficiency in terms of coordination. However, expectations are that the efficiency gains in terms of transaction costs are not as high as in the case where blockchain provides complete disintermediation. Considering such a hybrid model, in which blockchain solely has the function of an operational model, blockchain technology should be compared with existing operating systems that can be operated by the aggregator, such as Oracle databases and cloud solutions, to evaluate whether blockchain technology is a feasible operation mechanism for the aggregator.

7.1.4 Uncertainties in market size of flexibility from a decentral level

The rise of- and shift towards decentralised energy systems was a main assumption at the start of this research. In this research increase in prosumer activity and the increase of appliances that are able to provide flexibility, important requirements for enabling the deployment of decentralised flexibility, are expected. Following this assumption, a fair sized market for decentralised flexibility, a requirement for the success of the aggregator or blockchain application, can be assumed. The final market size of decentralised flexibility falls or stands with a number of factors though; prosumer involvement, the competitiveness with respect to other flexibility providing technologies, and the actual need for decentralised flexibility.

Regarding prosumer involvement, one could question what share of the population will actually become an active prosumer and is willing to trade its flexibility to the market. This will highly depend on the ease of use aggregation services could provide in the future, and the financial attractiveness of participating in an aggregation system. In the end, a model for decentralised flexibility will be compared by interested parties with existing flexibility mechanisms and will only be adopted by parties when proven to be at least as efficient or financially attractive compared to other mechanisms for flexibility. The business case of both aggregation systems is still uncertain though. Finally, one could question the actual need for decentralised flexibility. This is very dependent on choices made regarding the integration of European electricity markets and the development within future regulatory frameworks, which would lower the need for flexibility from a decentralised level.

7.1.5 Nuancing the potential of blockchain in the energy sector

Blockchain, defined by some literature as a system that enables complete disintermediation and decentralisation of sector, is currently being hyped to be the next big business revolution which impacts a broad variety of sectors. This research, however, shows that the impact of blockchain across sectors needs to be nuanced. Due to sector characteristics and the difficulty of disintermediation and self-organisation within the specific use case discussed in this research, blockchain cannot fulfil the complete potential as promised by blockchain- literature and enthusiasts. This research even concluded that blockchain technology might be considered as a coordination mechanism rather than a mechanism of governance. Yet, some blockchain applications, such as Everledger and Bitcoin, have proven to be successful in providing disintermediation. It is therefore necessary that each individual use case, in the energy sector and in general, needs to be assessed in detail to evaluate the added value of blockchain over existing technologies, governance- and operational structures. Only then, will the current hype on blockchain lead to the development of real and beneficial use cases.

7.1.6 Suggestions for future research

The focus of this research was on identifying design implications for the aggregator role and a blockchain application in unlocking decentralised flexibility from a system integration perspective. Considering the identified design implications on different layers, the bridge towards detailed design is made the classification of identified design implication in considerations in performance, boundary conditions, and future design variables. Considering the research results, and the discussion in previous sections, the following suggestion for future research questions have been formulated:

- What specific policy design is needed to resolve for current barriers for the operation of a decentralised flexibility model?
- What does a detailed design of the aggregator role in deploying decentralised flexibility incorporating system integration look like?
- What does a detailed design of a blockchain application in deploying decentralised flexibility incorporating system integration, look like?
- What is the effect of blockchain technology on operational efficiency of the aggregator role in deploying decentralised flexibility, compared to existing operational models?
- What could a blockchain assessment framework in the energy sector look like?
- How do aggregation systems of decentralised flexibility compare to other grid flexibility options such as interconnection, large scale energy storage and dynamic network tariffs?

7.2 Reflection on the research

This section provides a review on the results of this research by reflecting on the research objective, research relevance and quality of the research results in 7.2.1, 7.2.2, and 7.2.3 respectively.

7.2.1 Reflection on research objective

The research objective of this thesis was, *to identify system integrative challenges that arise from the aggregator role and a blockchain application in offering decentralised flexibility in the Dutch electricity sector.* This thesis indeed provides an identification of system integrative challenges for both the aggregator role and a blockchain application. However, a variety of challenges have been identified that need to be overcome and that need to be incorporated in future design. Comparing the aggregator role and the blockchain application, the aggregator seems to fit better within the current systemic- and institutional environment in the electricity sector. A blockchain application however could provide some major benefits in operational efficiency. Future research needs to find out what the detailed design of the aggregator role or blockchain application should look like.

7.2.2 Reflection on research relevance

This section reflects on the research relevance of this research by elaborating on the societal and scientific contribution.

7.2.2.1 Societal contribution

From a societal point of view, this research opted to contribute to the development of an integrative design for an aggregation system for decentralised flexibility. By identifying design implications, a contribution is made towards the integrative design of the aggregator role and blockchain application. This research provides insights on what implications need to be overcome, considered and decided on in the detailed design of both systems. Examples of this are removing technical-, regulatory- and market barriers, the assignment of clear roles and responsibilities and choices in network architecture, operating- and control strategies.

7.2.2.2 Scientific contribution

The reflection on the scientific contribution consists out of the aggregator- and blockchain exploration, and the scrutinizing and use of the CD framework.

Aggregator- and blockchain exploration

An opted contribution from the scientific point of view was the exploration of the aggregator role and blockchain applications. This research contributed in identifying challenges that arise from a system integration perspective. Whereas the work of USEF (2015) solely focuses on the specifics of a market model design, this research elaborated more in detail on the design, by identifying system integrative design implications. This research can therefore be considered as a continuation of the work of USEF. Other literature on the aggregator role in unlocking decentralized flexibility focused on either specific operating models (Biegel et al., 2014; S. Burger et al., 2016; Mahmoudi et al., 2017; Sandels et al., 2011; Sbordone et al., 2015) or the positioning of the aggregator role in the electricity market (Bessa & Matos, 2010; Carreiro et al., 2017; Dethlefs et al., 2015; Eid et al., 2016; Eid et al., 2015; Gómez San Román et al., 2011;

Ikäheimo et al., 2010; Lynch et al., 2016). This research can therefore be considered as deepening to continuation of previous literature as well. Only the work of Smart Grid Task Force (2015) provided insights in regulatory recommendations for aggregator operation. This research provides broader scoped insights in aggregator design implications and issues to be overcome, which is less detailed, but more comprehensive than presented in Smart Grid Task Force (2015).

The exploration of the blockchain application in this specific use case had a high added value. No system integrative analysis of blockchain technology to be implemented in a specific use case is present in current literature. This research therefore provides a first exploration on implications of the system integration of blockchain in an energy related use case. By using a system integration approach and mapping design implications, this research was able to provide a nuancing note beyond the current hype around blockchain (discussed in 7.1.5). More general system integration recommendations, mainly regulatory, already have been identified by C. Burger et al. (2016) and Lavrijssen and Carrillo (2017). The main recommendations from these two works was that governmental bodies should speed up blockchain development, revise the current regulatory framework, expand current use cases and business models, and to look beyond current roles and responsibilities to adopt blockchain technology in energy use cases. This research however, provides a more detailed overview on relevant implications for blockchain technology in energy use cases.

CD framework testing

By executing this research the application of the CD framework was subjected to a test. The CD framework originally aims to provide a support for system integration design for energy infrastructures. In this research, the CD framework was used as a support for the analysis where system integration in aggregation system might challenge design. The CD framework has proven to be very successful in structuring the analysis, identifying issues that play a role on different levels and aligning the relevant variables and issues of the technical and economical dimension. A few remarks can be made on scrutinizing the CD framework as described in Scholten and Künneke (2016).

A point of attention in the CD framework is the seeming misalignment between the systemic- and institutional environment, structured by the access design knob. In the technical perspective, the systemic environment comprises the level of technology- and knowledge and the system architecture and asset characteristics of the Dutch electricity sector. The institutional environment on the other hand concerns more general characteristics such as norms, values and religion and the polity, judiciary, and bureaucracy system and the competition law as applicable in the Netherlands. Whereas the systemic environment already focusses on the specifics of the electricity sector, the institutional environment is about more general concepts relating to the country specific institutions. This can be cumbersome for the alignment of the access design knob. Competition law and the polity system for example is considered very open in the Netherlands, which is not specifically true for the electricity sector, due to the embeddedness in strictly regulated environment. It is therefore advised to narrow the scope of the institutional environment to match the scope of the systemic environment. Considering the focus of the systemic environment on the general system architecture and asset characteristics, the institutional environment should focus on the competition law and characteristics of formal institutions specific for the general system architecture, and asset characteristics for the electricity sector. Adopting this change, the systemic environment should comprise the access to the general system architecture and asset characteristics from the techno-operational perspective, and the institutional environment considers the access to markets and the option of competition within the general system architecture and asset characteristics.

Another point of attention is the applicability of the CD framework for the actual design of energy infrastructures. The CD framework provided a high added value in the demarcation of the problem situation to be able to map design implications. However, after using the framework in this research, it doesn't feel like the CD framework, in combination with the consultation of the underlying principles in the different layers, is sufficient to work out a comprehensive design. This is mainly because of the lack of operationalisation and a specific design guideline. It is therefore advised to use the CD framework as a problem demarcation tool to stipulate where challenges of design pop up, and to subsequently switch to the detailed design approaches of system- and market design to have a more specific guideline for the actual design available. This also refers to the notion made by de Bruijn and Herder (2009) which state that the full integration of the system- and market perspective is essential but more or less impossible, and should be analysed and designed by designers who are able to switch perspective and apply both perspectives in a useful way.

Another point of attention in applying the CD framework is the lack of a prioritisation method of design variables. From the framework it remains unsure whether challenges as found in the layer of coordination are as relevant or important as challenges found in the layer of access. In order to get insight in the relative relevance of design implications in this research, a prioritisation was made based on the insights of the researcher insights. As the prioritisation in this research showed, the design implications as found in layer of access were considered as the most important ones. It might however be dependent on the specific scope of a research which layer or design variable might me the most important.

A final point of attention is the lack of a specific guideline in applying the CD framework. By executing this research, it sometimes felt that the CD framework provided less support than expected in advance. It is therefore advised to develop a guideline on the application of the CD framework in specific circumstances. In this research, the CD framework is used as a demarcation tool for identifying design implications for the opted system integration of a future energy infrastructure. A first draft of a guideline for this specific application is provided:

1. ***Provide a description of the environment to be designed in***. Depending on the 'to be designed' infrastructure, this should be done in either a broad or detailed manner. In this research it was chosen to provide a broad description of the design environment since this research was a first exploration of the system integration of the aggregator role and blockchain application. It was expected that they were at odds with the broad concepts of the sector as we know it now. When diving into a more detailed analysis or when it is expected that the infrastructures fit in with the current environment more easily, this step is in need for a more detailed description of the design environment. To structure the design environment, it should be described along the design variables of the framework; access, responsibilities, and coordination.

2. ***Conceptualise the infrastructure that is evaluated.*** In gaining more insights in concepts and characteristics of the 'to be designed' infrastructure, the infrastructure needs to be conceptualised. Step 1 and 2 can also be applied in reversed order. In this way, knowledge on the concepts of the infrastructure helps the researcher to elaborate on the most relevant concepts within the design environment.

3. ***Identify design implications.*** Evaluate concepts of the infrastructure subject to analysis, along the characteristics of the design environment in a top down order (from access, to responsibilities, and coordination). Identify implications, and where necessary, iterate by means of consultations, expert interviews or substantive deep-dives in literature. By adopting a top-down approach, implications that arise at the level of access can exclude or increase implication at lower levels of the framework.

4. ***Prioritise design implications.*** After listing design implications over several layers, prioritised design implications are needed to ensure the most hampering design implications are resolved with the highest priority. In this step it comes down to the researchers judgement and creativity to prioritise implications in a right way. As observed in this research, the layer of access was considered to have the highest priority since it significantly influences the other variables and layers.

5. ***Define design actions.*** This step is outside the scope of this research. This step should comprise the identification of concrete design actions that solve the challenges as identified in step 4.

6. ***Detailed design.*** Depending on the specific design actions as stipulated in step 5, detailed design should be executed by a systems design, or market design approach. As elaborated earlier on, the CD framework is not scrutinised in a sufficient way that it can be used to walk through a design cycle. It is however important to switch between systems and market design perspective to not lose the approach of system integration out of sight.

To conclude, the CD framework provides a useful system integrative framework. It is however argued that the framework itself lacks detail, operationalisation, and a design guideline to be used in the detailed design for system integration for energy infrastructures. Nonetheless, the concepts and underlying principles of the framework are considered valuable. It is therefore advised to use the CD framework more as a problem demarcation tool, as preliminary step for detailed design.

7.2.3 Reflection on the quality of the research results

This section reflects on the quality of this research by elaborating on the reproducibility, internal validity and external validity. The qualitative character of this research, the use of one specific analysis framework, the focus on a specific aggregator framework and applying that framework to the blockchain application, and the selection of expert interviewing, all induce some bias relating to the research results. The qualitative character of this research caused bias since it often reflects on the opinion and the creativeness of the researcher on what implications are found or are considered important enough to involve in the research. To prevent for this bias, the research is structured along an existing framework and validated, nuanced and complemented by means of expert interviews. Still, the research is subject to some reproducibility issues, since a different researcher might have a different view, might interpret the CD framework in another way, and organises the expert interviews in a different way.

By using the CD framework, a very specific conceptualisation of the system integration perspective was chosen. Because of all the interlinkages, alignment relations in the CD framework and path dependencies along the way, it was quite hard to isolate the elements of the problem situation, which made conducting a sound analysis sometimes really hard.

Furthermore, by analysing the problem situation and design implications, the research stuck to the principles as described in the CD framework. Using another assessment framework might for example lead to different outcomes as found in this research. Expert interviewing was used to create an as comprehensive analysis as possible. However, the experts in expert interviewing are subject to bias themselves as well due to different opinions and level of knowledge.

Following the considerations above, the conclusion can be made that the identified design implications in this research is incomplete and subject to bias. The research however provides a good first insight in high level design implications of the aggregator role and a blockchain application in unlocking decentralised flexibility. One needs to be careful by using this research in the detailed design of both systems, since new design implications could arise because of path dependencies and dynamics. It is therefore advised that a future research always keeps track of new induced design implications, originating from design choices along the way of the detailed design.

8 Conclusions

Due to the intermittent character of variable renewable energy sources, future electricity systems are in need for substantive flexibility options. The emergence of prosumers provides an opportunity to unlock flexibility at a decentral level, by using flexibility from prosumer-controllable load, generation, storage, and EVs. To have a significant effect on grid flexibility and to enable the trade of small flexibility capacities, some sort of aggregation system is needed. This research distinguishes the aggregator role and blockchain technology as conceptualisation of an aggregation system. Important in the implementation of such systems, is the ability to simultaneously align technical- and institutional design principles, referred to as system integration. It is expected that the system integration of both system is prone to many barriers and complexities. This research provides an analysis of design implications and challenges that might hamper the system integration of the aggregator role and blockchain application in unlocking decentralised flexibility. The main research question is therefore defined as follows:

> *Main research question:*
>
> **"What system integration challenges need to be overcome to enable the implementation of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?"**

To provide a sound answer to the research question, several sub-research questions are defined:

1. How can a system integration approach be conceptualised in the analysis of energy infrastructures?
2. What are relevant characteristics of the Dutch electricity sector to be considered in the system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?
3. How can the aggregator role and a blockchain application be conceptualised in the case of unlocking decentralised flexibility in the Dutch electricity sector?
4. What design implications arise from the perspective of system integration of the aggregator role and a blockchain application in unlocking decentralised flexibility in the Dutch electricity sector?

System integration approach

The system integration approach in this research is conceptualised by the CD framework as described by Scholten and Künneke (2016). The framework provides a structured way of classifying the electricity sector along 3 layers, access, responsibilities, and coordination, and two dimensions, technology and economy. The main focus of the framework is to provide a comprehensive design, describing how to achieve system integration in the design of energy infrastructures. However, in this research, the framework is used as a tool for analysing where the system integration challenges eventual design by considering the implementation of the aggregation systems in the environment of the Dutch electricity sector.

Characteristics of the Dutch electricity sector

To be able to define challenges of both aggregation systems in embedding in the Dutch electricity sector, the environment of the Dutch electricity sector was described along the layers of the CD framework by taking into account its current characteristics. The main notion to take into account in the system integration of both aggregation systems, is that in the current electricity sector access, responsibility, and coordination in the electricity sector, are structured and optimised along a centralised configuration. This potentially challenges the system integration of the aggregator role and blockchain application, since both can be considered as systems that are in need for a more decentralised approach and perspective.

Conceptualisation of the aggregator role and blockchain application

The aggregator model and a blockchain application are two opposing models in which the aggregator model is an intermediary role centrally organising a flexibility model and where blockchain allows for, disintermediation and self-organisation. In conceptualising the aggregator model for this research, the market model of the aggregator as described in USEF (2015) is used. Transactions in this model are coordinated with the intermediation of the aggregator, which provides prosumers with an incentive to offer flexibility. The aggregator model is characterised by formalised contractual relationships, central control, and the connection with the central national wholesale model. Blockchain is an innovative disrupting technology enabling the disintermediation of market structures and institutional environments. With the introduction of a transactional system on a distributed ledger that is immutable, unalterable, and highly secured, enthusiasts expect that the intermediation of a trusted third party (such as the aggregator) is superfluous. Blockchain is characterised by automatic coordinated and executed transactions, based on smart contract logic, which enables automatic matching of suppliers and consumers of flexibility without intermediation, ultimately potentially lowering transaction costs.

Design implications of the aggregator role and blockchain application

The system integration of both the aggregator role and blockchain implication induce a variety of design challenges. A model for decentralised flexibility operated by the aggregator is at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector. The role of the aggregator as market intermediary however fits current sector parties. Central steering by the aggregator allows rules, roles and responsibilities to be assigned very specific. This however implies a strong formalised relational environment causing a high degree of complexity in operation and interaction which increases transaction costs. At an coordination level, many complications in the operations and control of transactions are present.

The model for decentralised flexibility operated by a blockchain application is both at odds with the current centrally configured regulatory-, and legislative environment of the electricity sector, as well as with the role of current parties operating in the sector. Due to disintermediation, it is very hard to assign specific roles, rules and responsibilities. Organising the blockchain in a private network, implementation of steering- and regulating mechanisms is possible. Private blockchains however oppose the full potential of disintermediation and self-organisation. Blockchain is not in need of formalising relationships, making coordination less complex, which has a positive effect on transaction costs. However, also in a blockchain application, many coordination complications in the operations and control of transactions are present.

Design implications as identified in this research have been classified in three categories; design implications that define the considerations between both aggregation systems on different performance indicators, design implications that need to be resolved to enable the successful implementation of a flexibility model at a decentralised level, and design implications that need to be further elaborated on in the detailed design of both aggregation systems.

Consideration of design implications on the aggregator and blockchain performance
The design implications in this classification elaborate on the considerations of the aggregator role and blockchain application on several performance indicators. It reflects on how the aggregator and blockchain application perform differently on challenges as identified in this research. As can be seen in Table 8-1, the aggregator and blockchain application both perform differently on different indicators, based on their specific characteristics. Differences in performance can be used for policy makers and potential developers to evaluate what system generates the best outcomes in a specific situation.

Table 8-1: Performance indicators of the aggregator and blockchain application

	Aggregator	**Blockchain**
Fit with current environment	At odds with current sector because of decentral sources, but the role of the aggregator fits within current business models due to the centralisation of organisation	At odds with current sector and activities of established parties due to the use of decentral sources and disintermediation of organisation
Technical complexity	Technically relatively mature. Many use cases, much written on in the literature	Technically very immature. Few use cases, technology is emerging and complex
Governance	Central organisation that manages the linkage between prosumers and central markets	Technology automatically manages the linkage between prosumers and central markets
Regulating ability	Because of central organisation relatively easy to regulate and implement steering- and safeguard mechanisms	Due to disintermediation uncertain how the activity within the blockchain can be regulated
Coordination complexity	Formalised relationships with a lot of complexity and interaction	No need for formalisation of relationships due to the usage of smart contracts
Transaction costs	Significant transaction costs due to complexity	Relatively low transaction costs due to efficient coordination

Design implications that need to resolved
Design implications that need to be resolved refer to current technical-, regulatory-, and market barriers in the electricity sector that hamper a flexibility model at a decentralised level. These design implications are relevant for both the aggregator as blockchain application to be removed, or significantly improved to enable these systems to successfully emerge. The technical barrier that needs to be overcome relates to the lack of standardisation of the aggregator role and blockchain application in unlocking decentralised flexibility. Technical progress, use cases, and pilot projects are needed to draw lessons learned for a large scale flexibility model at a decentralised level. From a regulatory perspective, many implications need to be overcome to enable system integration of the aggregator role and blockchain application. Design implications, as identified in this research relating to regulatory barriers, are: the revision of current roles and responsibility, central tendency in the current regulatory environment, unclear definition of the product of flexibility, and lack of prosumer involvement. There is also a need to remove several market barriers that disadvantage decentral means such as the aggregator role and blockchain application compared to traditional means

Future design choices

Some design implications only become relevant in the detailed design of the aggregator role and blockchain application respectively. The listing in Table 8-2, provides an overview of future design choices originating from the design implications, as identified in the analysis in this research. The purpose of this listing is to gain an insight in design variables that need more detailed specification in the phase of detailed design of both aggregation systems.

Table 8-2: future design choices

Aggregator	Blockchain application
Specific roles and responsibilities	Specific roles and responsibilities
Specific rules and regulation	Specific rules and regulation
Aggregator control strategies	Specific design of blockchain platform
Aggregator incentive strategies	Blockchain control strategies
Safeguard of data privacy and security	Specific network typology
	Safeguard of data privacy and security

Discussions and suggestion for future research

In comparing design implications, both aggregation systems have their advantages and drawbacks. Choosing for either the aggregator model or a blockchain application is not per se based on evaluating which system outperforms the other, but more on preferring the characteristics of one system over another. The main considerations seem to be the centralised aggregator model where steering- and safeguards instruments are easy to be implemented, versus the decentralised and seemingly more efficient coordination model of a blockchain application. In reviewing the design implications, the aggregator role therefore seems to provide more desirable outcomes compared to the current environment of the electricity sector. Besides, the aggregator role allows for more structured regulation, roles, rules, and responsibilities. Blockchain on the other hand, enables for efficient coordination, due to the automation and disintermediation of the transaction. However, in this specific use cases, a degree of centralisation of the blockchain application is necessary because of the need for a private network topology, trusted party in charge of blockchain coordination, specific roles and responsibilities regarding blockchain development and operations, and the linkage to the national electricity market. Blockchain therefore cannot provide the full potential of disintermediation and self-organisation as promised by literature. Considering this, the main benefits of a blockchain application can be achieved in the level of coordination. Whereas some literature states that blockchain precludes the existence of third-party intermediaries, this research concludes that blockchain might in fact serve as a operationalisation of a third-party intermediary in some sort of hybrid model. Considering above, this research nuances the potential of blockchain technology as a method of disintermediation.

Considering the results and discussion of this thesis the following suggestions for future research are made:

- What specific policy design is needed to resolve for current barriers for the operation of a decentralised flexibility model?
- What does a detailed design of the aggregator role deploying decentralised flexibility incorporating system integration look like?
- What does a detailed design of a blockchain application deploying decentralised flexibility incorporating system integration look like?

- What is the effect of blockchain technology on operational efficiency of the aggregator role in deploying decentralised flexibility compared to existing operational models?
- What could a blockchain assessment framework in the energy sector look like?
- How do aggregation systems of decentralised flexibility compare to other grid flexibility options such as interconnection, large scale energy storage and dynamic network tariffs in terms of affordability, availability and acceptability?

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Appendix A: Expert interviewing

This appendix elaborates on the application of expert interviewing in this thesis by discussing the method of interviewing used in this thesis, the selection of interviewees and the worked out summarised interviews.

Interviewee selection

System integration is the leading perspective of this research. The interviewees in this thesis are therefore selected upon their ability to review both aggregation systems and their design implications from a system integration perspective and vary from a professor in energy market regulation to a CTO of a Dutch DSO, academics, blockchain experts for energy related applications, and energy consultants. The interviewees selected represent a broad level of expertise, varying from regulation to electricity markets, blockchain technology, decentralised energy systems and the energy transition. For a complete overview of the selected interviewees and their job title and expertise one can consult Table 0-1.

Table 0-1: Overview of interviewees

Name	Job title/Expertise
Cherrelle Eid	PhD researcher on Smart Grid Policies at Delft University of Technology
Theo Fens	Senior Research Fellow at Delft University of Technology and consultant on energy matters at Deloitte (associate partner)
Richard van Gemert	Research fellow at Delft University of Technology on the energy transition. Managing partner and expert sustainability at Driven by Values
Sjors Hijgenaar	Blockchain expert in energy transition at CGI
Jeroen de Joode	Senior Inspector Energy at ACM
Machiel Mulder	Professor regulation of energy markets at University of Groningen
Roelof Reineman	District heating- and blockchain expert at Eneco
Guy Rutten	Energy consultant at SIA Partners
Jeroen Scheer	CTO at Alliander
Leon Straathof	Advisor energy transition at Straathof Advies

Interview method

Because of the difference in expertise of the interviewees and their different level of knowledge on the concepts of the aggregator and blockchain, the interviews in this research are characterised by a semi-structured structure. Results from the interviews are used for nuancing, validating and complementing the design implications as found by the researcher. As seen in the analysis in chapter 6, the results from the interviews represent quite a large chunk in the analysis of design implications of both aggregation systems.

Regarding to the semi-structured structure of the interviews, no detailed survey list was composed at front. However, for each layer as found in the CD framework, some implications from the initial analysis were written out. The objective was to elaborate on each layer, access, responsibilities and coordination, in the individual interviews. Depending on the specific expertise or level of knowledge individual interviews most often was centred along one specific layer, however in general all layers were discussed in sufficient detail.

Summaries

This section provides summaries of the expert interviews as used in this research. The interviewees have given their written consent on publishing the summaries as presented in the remainder of this section.

Cherrelle Eid

Access

The aggregator-role is slowly emerging for end users located at the distribution grid and already a big step for the energy sector. A direct innovation towards a blockchain application can therefore be considered as too radical. The acceptation from the end consumer for a blockchain application can be considered as a barrier. Blockchain however can be considered as a possibility for an efficient way of dealing with the role and operations of an aggregator.

Responsibility

The aggregator role is a role not worked out in detail yet. Roles and responsibilities therefore still need to emerge. A key is that regulatory frameworks need to be adapted to be able to adopt new roles such as the aggregator.

The aggregator is characterised by several activities (from data management to physical aggregator and market clearing). It is necessary to evaluate what party can fill in what activity (for example, the DSO, an independent aggregator or another entity). This doesn’t necessarily need to be assigned to one specific party. Furthermore, the role of data management is a very sensitive activity and might require a regulated party (like the DSO) to be made responsible.

Prosumers might generally not want to bear the responsibility of flexibility offering or some sort of program responsibility. It is therefore necessary to have a trading agent operating on behalf of the prosumers.

Coordination

The Blockchain technology is an operationalization of the role of the aggregator role in which blockchain is considered as a coordination mechanism. This basically provides the aggregator a way to become more efficient. In a competitive market, an aggregator can distinguish itself from other aggregators by means of a blockchain operationalisation.

Theo Fens

Responsibility

With a proper functioning blockchain, there is essentially no need for the role of the aggregator for both forecasting as well as settlement. However, the program responsibility within a blockchain should be assigned to an actor, this could for example be an aggregator (or a distribution network operator for that matter) since prosumers do not want to bear this responsibility.

Because of slow processing speeds associated with a global blockchain implementation and issues of scalability, a local (based on a geographical area) blockchain solution with a smaller network and less nodes may be an efficient solution. The aggregator can be the operator of a private network in this configuration. With a trusted party operating the blockchain, the issue of trust is not the main justification for using a blockchain.

The expectation is that the product of flexibility will become very important for the security of supply in the electricity sector. One could think of organising flexibility as a utility product as it is currently used in the balancing mechanism by the TSO. One way of doing this is cascading the flexibility mechanisms as we know it at the TSO level down to the DSO level where the DSO could locally balance the distribution grid.

Flexibility may be organised in a local retail market decoupled from the APX wholesale market.

Coordination

The market mechanisms of flexibility are very much related to supply and demand. At the level of the distribution grid one should come up with the right signals. For a blockchain application it should be defined how local balancing can be coordinated in smart contracts, this may well be a regulatory issue.

It is expected that the market for flexibility is not that big, especially when the commodity of electricity becomes a marginal product in the context of abundant renewables and storage. The economic value of flexibility will therefore not be very significant. Considering this, a blockchain application might be more desirable because of its low costs for transactions and thereby no need for an expensive aggregator.

All the measurement equipment and paying the network validators that are needed for real-time smart contract operations add up to the transaction costs in a blockchain application. The actual transaction costs are therefore unknown. Measures for keeping transaction costs as low as possible concerns the size of the blockchain, a localised (private?) blockchain may well be an economically viable solution.

Richard van Gemert

Access

Energy sector is currently not ready for the implementation of both systems. Parties however are looking into these type of solutions.

Responsibility

Institutionally, there is no design yet that enables the deployment of both systems. We need to look in new institutional designs that allow such systems to be deployed. Important is to look beyond current roles and responsibilities

The role of the aggregator needs to be an independent role, this not necessarily means that it should become an utility. But it is not desirable to organise this in a competitive way because of the importance of flexibility in the future.

The DSO can be involved in the flexibility steering of congestion management. Very important to operate this by capacity flexibility (e.g. a DSO communicates the capacity available on the distribution grid) and not the flexibility of electricity supply.

Coordination

In a blockchain application, the linkage of the physical product of flexibility with the transactional blockchain system is difficult. It's very hard to make it traceable from feed-in to consumption. In practice, line losses and deviations from the promised feed in can occur. It's very uncertain how this is corrected for in blockchain technology.

Blockchain can also be considered as an operationalisation of the aggregator role where the aggregator aggregates independent blockchains and the information which is embedded in that blockchain to come to a flexibility price. The DSO can be connected to this blockchain where it passes on information on grid capacity. The aggregator can where necessary embed a time-of-use price in the transaction of flexibility suppliers and consumers.

Sjors Hijgenaar

Responsibility

Prosumer are capable of defining their preferences, but not on strategies to bid in their flexibility. Some sort of service provider is needed in providing the linkage between prosumers and the flexibility market. This is where new roles will emerge that can be adopted by current established energy retailers that might lose business because of the decentralisation of the energy sector.

Scalability of a blockchain solution is mainly dependent upon the number of nodes in the network.

It’s basically impossible to have a public blockchain configuration in the presence of a physical infrastructure such as the electricity sector. Because of the critical function of the electricity sector there is a need to have some sort of accountability present in the blockchain network. There should be safeguards to enable action against those that bring the operation of the grid in danger. This also generates trust among other market players and consumers.

Coordination

It is currently unknown what right pricing mechanisms would provide the efficient supply/demand mechanisms of flexibility.

The system of the aggregator can be very complex (because of the increasing trend of decentralisation) and expensive in terms of operation. Operation and transaction costs are very high because of the need of significant computer power. In a blockchain operation, the need for computing power is distributed over the entire network.

Jeroen de Joode

Access

ACM has regulatory oversight over the actors in the energy sector. As part of its duties ACM reviews how activities fit in within the current legal and regulatory framework. Sometimes activities contributing to the energy transition are performed by market actors that are not allowed to do so under current regulatory frameworks. ACM is looking into interpreting current frameworks in such a way, activities contributing to the energy transition can be placed within that frameworks. Unlocking decentralised flexibility is seen as an important condition for an energy transition at the lowest cost to society. So far the aggregator role got ACM its attention and access to the market is considered as important. However the goal is not to facilitate independent aggregators at all cost, but to allow for access to the market for all actors in a level playing field. This role of aggregators could also be established within the roles and responsibility of current parties and the current framework.

Currently, there are some signals that market access for new aggregation entrants can be problematic to smaller/local parties because of the requirements associated with obtaining a retailers license with ACM and program responsibility with Tennet, and because of some minimum technical market requirements. The ACM is going to explore whether these requirements are a barrier for potential entrants to access the market. When this is the case, we will analyse and implement potential remedies within the regulatory framework and when relevant advise the Ministry on adaptations in the legal framework. An example of such a policy instrument is the creation of a 'license light'. Such a 'license light was part of an earlier proposed law (STROOM) that was halted in the First Chamber of Parliament.

Privacy and security issues can form a major barrier on the side of the prosumer. Nowadays, data driven application such as the aggregator role and a blockchain application face major attention when it comes down to data management. Prosumers will be suspicious towards the way data is being managed in both systems. However, there can be expected that this is a bigger issue in the case of a blockchain application since this is a disruptive unknown type of technology. Maybe blockchain could therefore only serve a niche market for prosumers interested in blockchain technology.

Big established energy retailers are not yet used to going into decentral solution such as an aggregation system. However it can be expected that once it is proven that this can be a viable business, all established parties will evolve a business in decentral solutions. A trend is already notable with initiatives such as Powerpeers and Peeks.

Responsibility

ACM considers the market for aggregation to be sufficiently competitive as the retail market in the Netherlands also shows sufficiently competitive levels. The entrance of new actors with aggregation services would even add to this . This could make the sector robust to opportunistic behaviour related to market power. When profit margins will become too large, other aggregators potentially take over the market share of that particular party. This is based on the assumption of sufficiently large switching behaviour of consumers. This is still a bit of an issue in the current retail market as a large share of retail customers has never switched supplier since the start of market liberalisation although price differences between retail suppliers can be large..

A big issue in a blockchain application is the assignment of specific responsibilities when coordination and decisions are managed on a decentral level. Within an aggregator model, these responsibilities are assigned to the aggregator. How this relates to a blockchain application is uncertain. Currently, legislation is not able to deal with this issue of blockchain technology.

The flexibility brought to the market by aggregators can serve roughly 3 markets: congestion management for DSO, portfolio optimisation of BRPs and balancing mechanisms for TenneT. Important for the efficiency and competitiveness is that the flexibility product could be offered in all these 3 markets. There should therefore always be a linkage to national wholesale markets. In the case where only a local market is considered without a link to the national system and the price signals stemming from the national markets, a suboptimal situation is created.

Coordination
Considering that the flexibility product is most efficiently offered in 3 markets it's uncertain how an aggregation system deals with conflict signals from the different markets. How can the system deal with the sitation TenneT is in need for flexible supply, but the distribution grid is limited and the DSO sends a counter flexibility signal. The fact that there are differing signals is not a problem as they signal different energy system needs, the issue is whether the allocation of flexibility at each time interval can be done efficiently, responding to these signals.

Market activities
In the end, the aggregator and blockchain could compete with each other. The application which eventually offers the best client solution is expected to gain the biggest market share.

DSOs can fulfil a facilitating role in decentralised flexibility when it provides insight in where flexibility is needed the most, thereby indicating the value of flexibility at specific locations.

Machiel Mulder

Access

The trend of decentralisation is quite unsure since we finally have a well organised European electricity market with less and less restrictions on interconnection. Only a small trend to decentralisation is notable with more and more small players become active. This is however insignificant with only a maximum of 10% of the electricity consuming population. Consumers do not have the desire of demand response activities in which an aggregator or blockchain application steer their energy behaviour. Prosumers therefore do not feel the urge to participate in these type of activities. It can therefore be expected that the market of aggregation is relatively small.

Besides, there is no strong trend in the Netherlands towards decentralisation with the implementation of large central wind farms on- and offshore. Imbalances on the DSO grid are therefore negligible.

Responsibility

Current flexibility mechanisms at the wholesale model have proven to be sufficient. There is therefore no need to establish a new type of flexibility mechanism on a decentralised level. When imbalances on the distribution grid occur it's the responsibility of TenneT to solve this.

The need for flexibility is more urgent for the central wholesale markets. Congestion management might be in need for local solutions, but this is already embedded in the current responsibility of the DSO.

The activity of aggregation is clearly a competitive activity, as no monopolist characteristics or economies of scale are related to this activity. Besides, there is no public activity involved, blockchain technology and the aggregator are a technology and an organisation respectively. No need to let this be a regulated activity.

Expectations are that the aggregator role or blockchain technology are activities which are going to be fulfilled within the activities of current energy retailers. There is therefore no need to redefine the roles and responsibilities as we know now.

Coordination

New innovative solutions such as the aggregator role or a blockchain application need to be compared with the elements of flexibility currently present in the electricity market.

Another way of dealing with congestion management for the DSO is the introduction of dynamic network tariffs where usage of the distribution grid is penalized at times disadvantageous for grid utilization. Important in establishing dynamic network tariffs is the fairness towards society, where higher returns because of the dynamic network tariffs need to flow back towards society.

Market activities

In the end, new applications such as the aggregator role and a blockchain application will only be adapted when they proof to be more efficient than the current system elements.

Roelof Reineman

Access

Decentralisation and peer-to-peer markets will become very important in the energy transition. The role of energy retailers will therefore be subject to change. Those that are not able to adapt this change will encounter difficulties in maintaining their market position. Parties and consumers are not ready for some sort of decentral management yet.

The role of the aggregator could be considered as an intermediation solution with introducing a party with lag, the need for agreements and the possibility of fraud. The aggregator could therefore be considered as a step forward, but not as an end-game. The aggregator can subsequently be made more efficient by means of the blockchain. This however very path dependent. At this moment, blockchain is still a step too far, especially a public blockchain.

Responsibility

Regulations in a blockchain is hard. Legislation is not ready to facilitate this.

Aggregator should be place as a service within the current market. This could however be operationalised by blockchain. The energy retailers eminently are the parties that could develop this function. Responsibilities then can be regulated via the service provider.

Blockchain could provide energy retailers with a future proof business model in a decentralised energy sector.

Guy Rutten

Access

Current market mechanisms have to change when we consider the implementation of an aggregator role or a blockchain application. Currently, the system is too much focussed on the central configuration of the energy sector. The Ministry of Economic affairs is also very conservative in initiating new type of systems such as the aggregator role or a blockchain application.

Responsibility

There is a need for a service provision in providing prosumers with smart contracts. This enables current parties to establish business round a blockchain application.

Jeroen Scheer

Access

An end application for the prosumer needs to be easy to use and safeguard privacy issues related to data. For the prosumer, it doesn't really matter whether this is facilitated by the aggregator or blockchain technology. The question however is whether prosumers give their consent on the exchange of individual data.

The current tendency is that traditional parties evaluate everything from their current role and perspective.

Responsibility

Within a public blockchain you have the a self-organised organisation whereas a private blockchain allows to assign certain responsibilities to specific parties. In a private blockchain, trust between participating parties is easier to accommodate. The question however is who is allowed to be in charge of a private blockchain. Market parties and energy retailers won't accept the DSO as the one in charge as they see them as a competitive party and a way to extend their business. Strict regulation of a blockchain application is not necessary since it is a self-organising technology. Rules to guide to blockchain would be sufficient.

The USEF aggregator framework has a strong linkage with the national wholesale model. The aggregator is therefore in need of all sorts of data to operate their business; commercial portfolio data, DSO data and data of individual prosumers. Without the incorporation of any safeguards or regulation, the aggregator than can easily manipulate market outcomes. Imagine the situation in which an energy retailers is also in charge of the role of the aggregator and therefore has insights on points of congestion and prosumer data to optimise its own portfolio.

USEF generates one price based on the national wholesale model. But locally, different prices for flexibility arise. The aggregator model in USEF is not able to reward- or penalize local desirable- or undesirable behaviour. To enable this the price of flexibility need to be decoupled from the APX national wholesale model.

The responsibility for the development of a blockchain application is uncertain. A stimulation could be an open data platform in which parties can develop some sort of app and if they satisfy certain criteria and requirements they can be allowed to operate on the market. EDSN than can possibly operate as the so- called trusted party which oversees the whole process.

There is a need for a party that can make the linkage between prosumers and their preferences with a blockchain platform.

Coordination

Congestion management from the DSO can easily be put in smart contracts on a blockchain application where the physical limits of the distribution grid can trigger the transaction of a smart contract.

Opportunism is more a problem in the aggregator role than in a blockchain application. In the competitive aggregator role, the party in charge will strive for profit maximization. In a blockchain application, transactions are triggered by smart contracts. A higly opportunistic smart contract will basically not be triggered because of the merit-order effect.

System- and market activities

The market of flexibility is not as big as expected.

There should be room for experiments to explore the unknown. For DSOs, the involvement of market parties is necessary.

Leon Straathof

Access

The inertness of the energy sector is a barrier for decentral energy solutions such as the aggregator role or a blockchain application in unlocking decentralised flexibility. Especially blockchain technology will change the energy value chain compared to the value chain as we know it now. However, the established parties have a tendency to stick to the usual responsibilities and activities. This is maintained by the fact that the established parties who are in a leading position in steering groups etc.

This characteristic causes the energy sector to lack a pro-active and progressive attitude when it comes down to innovation. There is a need for a coordinated, programmatic approach in guiding the sector in the energy transition.

The aggregator role fits better within the current assets and configuration. Blockchain technology can therefore be seen as a second phase in innovation, an update of the aggregator role (only when it is an efficiency gain compared to the aggregator role).

For the end consumer, the prosumer, ease-of-use in the end application is very important. The average prosumer probably doesn't care about supplying flexibility.

Responsibility

Since the end consumer doesn't care about supplying flexibility, a service provider could emerge to make the linkage between the prosumer and the flexibility market. The big question is what type of parties are willing to try to take the lead in establishing such a service.

In establishing new innovative systems such as the aggregator and a blockchain application the energy sector need to look beyond current roles, and responsibilities. Regulation should therefore be adapted to create room for innovations and the unknown.

Flexibility can evolve as a public task. However, the main question is whether it's the most efficient way to organise this as a public activity or competitive activity.