Decentralised Local Energy Markets

Evaluating the Impact of Blockchain Technology on Local Energy Markets

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Master Thesis submitted to Delft University of Technology in
partial fulfilment of the requirements for the degree of
Master of Science
in
Management of Technology
Faculty of Technology, Policy and Management

To be defended in public on November 23ᴿᴰ 2018

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Abstract

Uprising innovative technologies like blockchain and the Internet of Things are increasingly changing the energy domain. These disruptive technologies are becoming more mainstream as a result of media attention and are supported by large multinationals like Tesla and Google. This combined with the enormous CO_2 emissions due to fossil fuels and increased number of black-outs has resulted in a growing societal need for self-owned and self-generated renewable energy. More and more communities are forming intending to produce their own energy and to sell their excess energy to their neighbours via local energy markets. This concept of local energy markets can theoretically be realised via the use of a blockchain. However, the manner in which and by whom this ideally shall be done is inconclusive. This research aimed to identify how the proposed business models are impacted by the blockchain facilitating local energy markets. This was done by stress testing the innovated business models against the identified uncertainties and scenarios that the blockchain and the transitioning energy domain bring forth. It was found that the business models of the Distribution System Operator and Supplier are despite several challenges feasible whereas the business model for the commercial/industrial prosumer is not and is advised to make a market entry at a later stage.

Keywords: Blockchain, Local Energy Markets, Local Energy Systems, Business Model Innovation, Business Model Stress Test

Acknowledgements

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Executive Summary

The energy domain is in a state of transition. The traditional top-down system in which a central production of energy services a passive consumer is shifting towards a smart grid with involved self-generating prosumers (producer and consumer). This transition is driven by a societal demand for action towards a sustainable energy landscape as a result of climate changes due to immense CO_2 productions. Incentivising consumers and prosumers to shift their energy demand favourably is therefore of top priority.

Considering this need for self-generated and self-owned energy, the notion of local energy markets was brought to life. In the current architecture of the grid, excess self-generated energy is being fed back into the grid and used to supply other households who are in need of energy. This is done against a fixed tariff which leaves the prosumer with little incentive to produce more and even less for those considering to take upon the role of a prosumer. The idea of a local energy market empowers the prosumer both financially as well as socially. By empowering the prosumer and facilitating a local energy market, a virtual power plant can be created servicing the actors of the future smart grid as well as the prosumers participating in the local energy system. The local energy market shall allow the prosumer to trade their excess energy with their peers providing them and others with an incentive to invest in renewable energy.

In order for this market to function well, the use of blockchain is considered. Blockchain technology offers a digitally distributed ledger which allows for the storing of transactions among the participants of the local market. Moreover, via the implementation of smart contracts the policies underlying the market can be enforced. This theoretically allows for smooth and secure transactions. However, the fact that blockchain technology brings forth the potential to facilitate this local energy market in an efficient manner, the manner in which this is to be done and the exact value proposition it brings is inconclusive. This raises the question upon which this research was based, namely:

<div align="center">

'How does blockchain impact local energy market business models?'

</div>

The goal of this study is thus to identify the impact of the blockchain on the business models of the actors considered taking upon the aggregator role to facilitate local energy markets. This shall provide managers and decision-makers of the actors with the ability to better assess the feasibility of facilitating decentralised local energy markets.

In order to examine how the blockchain can be facilitated there has been chosen to make use of the business model stress test method proposed by Bouwman et al. (2012). This method follows the following six steps:

1. Selection and description of Business Model

2. Selection of uncertainties

3. Mapping of business model components to uncertainties

4. Heat Signature

5. Analysis

6. Improvements & Actions

In order to fulfil the first step, business model ontologies were examined which resulted in the decision to make use of the Business Model Canvas in addition with the Value Proposition Canvas ontology to represent the business models of the relevant actors, and provide more background to the environment in which they are set. For the second step, a literature review was performed to establish characteristics and elements of local energy systems, local energy markets and the blockchain technology. This resulted in a proposed technological architecture of the local energy system by synthesising the (local) energy domain with the blockchain domain. This allowed for a trend analysis which identified the most relevant trends concerning this research. By clustering these we found six uncertainties, namely: Scalability, Complexity, Energy Cost, Implementation Cost, Privacy and Adoption.

Before performing the third step, the most relevant actors needed to be identified. After analysing the energy value chain and innovating it to a suitable representation of the local energy system context, there were defined three possible aggregator roles. These are the Distribution System Operator (DSO)-Aggregator, Supplier-Aggregator and Prosumer-Aggregator. Finally, the business model canvasses and value proposition canvasses for these actors were provided. The business model components and uncertainties were then mapped which provided a heat map template used to examine the weaknesses and assess the robustness of the innovated business models. The heat maps resulting from the business model stress test are depicted in the figures below.

DSO & Supplier	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Value Propositions	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Channels	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Customer Relationships	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Revenue Streams	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Key Resources	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Key Activities	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
Key Partners	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
Cost structure	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12

Heat Map of the DSO & Supplier

Prosumer	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Value Propositions	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Channels	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Customer Relationships	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Revenue Streams	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Key Resources	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Key Activities	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
Key Partners	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
Cost structure	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12

Heat Map of the Prosumer

After the stress test, there were performed analyses on the sub-views of the heat maps followed by a pattern analysis and a cross-comparison of the heat maps. Below a visual representation of the most critical business model components is provided for the actors.
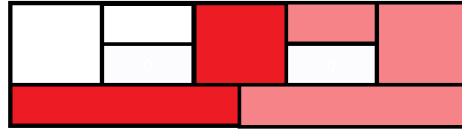
Overview of the Impact on Business Model Canvas Components DSO & Prosumer
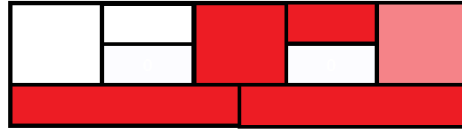
Overview of the Impact on Business Model Canvas Components Prosumer

The figures depict the most critical vulnerabilities of the two business models visualised in the Business Model Canvas. The DSO and Suppliers business models are heavily impacted on the Cost Structure and Value Proposition components and less on the Customer Segment, Customer Relationship and Revenue Streams. Similarly, the Prosumer business model is impacted in the Value Proposition and Cost Structure components but more heavily on the Customer Segment and Customer Relationship components. This has led to recommended improvements and actions for future decision-makers. In the following table these are presented:

Recommended Improvements and Actions

Action	Actor(s)
Research Regulations	DSO, Supplier, Industrial/Commercial Prosumer
Perform Blockchain Experiments	DSO, Supplier, Industrial/Commercial Prosumer
Perform Market Research	DSO, Supplier, Industrial/Commercial Prosumer
Incentivise Partners	Industrial/Commercial Prosumers

Considering the (economic) power of the DSO and Supplier relative to the Industrial and Commercial Prosumer, the feasibility of performing sound blockchain experiments was considered to be low. This resulted in the recommendation to postpone market entry until the 'Early Adopters' phase is reached. This in contrast to the considered feasible market entry of the DSO and Supplier as 'Innovators'.

The main findings in this study are the proposed architectural layouts of the local energy system, local energy market and their sub-systems. Second, the research identified the most suitable blockchain set-up to be able to facilitate the local energy market. Third, as a result of the business model stress test a mapping of the vulnerabilities and overall robustness of the three innovated business models has been provided. The innovated business models can furthermore also be made use of by future decision makers in the industry for strategic planning. Last, recommendations and improvements to the successful implementation of decentralised local energy markets are provided.

The limitations of this research are mainly related the qualitative nature of the research and the limited complexity that the business model canvasses can convey of the energy industry. Furthermore, the bias due to the low number of expert judgements limits the validity of the research. Recommendations for future work are therefore made towards the replication of the findings of this research. This is recommended to be done by conducting interviews with preferably a larger group of experts. Last, as the research touches upon many disciplines it is advised to further research the proposed technological architectures, the blockchain and market research.

1 | Introduction

Energy production, consumption and the growing advancements with regard to systems like the smart grid have increasingly been topics of discussion in recent years. Concepts such as the smart grid are becoming more mainstream and the efforts of companies such as Tesla (Morris, 2018) to provide solutions to energy black-outs are headlines in today's newspapers. However, the rate of penetration of renewable energy sources is questionable and environmental issues are still prominent. One example of this is the high CO_2 emission levels(Nejat et al., 2015) due to the consumption of fossil fuels, which is at the moment far from the intended levels and are likely to not be going down any time soon (Detlef P. van Vuuren, 2016). Even the Netherlands, to many an innovative progressive country, has difficulties successfully implementing policies to address the growing societal concerns properly, as they are in need of the support of the multinationals controlling the industry (Groep, 2017).

As a result of the rapid growth of the energy consumption and lack of action, there has been a growing societal movement demanding sustainable and self-owned energy(van der Schoor and Scholtens, 2015)(Hoppe et al., 2015). Salience and self-consumption will provide 'double-dividend' for prosumers. This notion of double-dividend entails that, as prosumers consume their self-produced energy they will also tend to shift their energy demand favourably lowering the demand during peak hours and benefiting from a reduction in energy cost (Keirstead, 2007). Furthermore, with the emergence and due to the benefits of the Internet of Things (IoT) this shall be made significantly easier in the foreseeable future. For example, one can think of smart meters that allow you to see when there is a peak in energy price and thus choose to not use certain electrical devices during this time period, or let the device decide this for you. This behaviour increasingly spills over to the local community, especially in the case where they have the ability to trade their self-generated energy and be financially compensated in doing so. This movement towards local energy systems has the potential to significantly impact the current energy system, leading to a potential death spiral for the transmission and distribution industry (Laws et al., 2017).

Another high potential and potentially disruptive technology is the blockchain technology. The blockchain technology is most known from its initial implementation: the Bitcoin (Nakamoto, 2008a), which, mostly due to its rapid growth in price, has become a term few have not heard of. The blockchain is the technology underneath the Bitcoin facilitating the cryptocurrency. As the technology essentially is a digitally distributed ledger recording transactions of its users, the blockchain can be implemented in many other manners and industries. One of which is the energy industry, and more specifically local energy markets. A local energy market refers to a local market in which the community of a microgrid can sell and buy excess self-generated renewable energy via a market mechanism powered by the blockchain technology.

Local energy markets provide the community of a local energy system with an alternative to the current only option which is feeding their excess energy back into the grid against a fixed tariff. As a result, prosumers and especially consumer are given little incentive to invest in Renewable Energy Sources (RESs). Besides the economic aspect, the social aspect is of importance as well. As communities form and trade their excess energy, the gains can be kept within the community empowering its members. Moreover, it is possible to for instance set-up charity models to support the less well-off.

Bidmon and Knab (2014) argue that in order to substantially improve the energy transition there shall have to be made innovations that are not just technology-based. This specifically refers to the innovation of business models, underpinning the importance of appropriately innovated business models to develop niches. Considering the increasing rate of consumers-turned-prosumer there shall not only have to be made innovations to business models, but there shall also have to be developed new business models. This is due to the fact that the prosumer, especially in the context of local energy markets, is to be considered part of the business venture. The prosumer shall, due to this transition, likely be increasingly integrated within these business models and play a more central role in the future energy domain. This research shall focus on assessing how decentralised local energy markets can bring value to the industry and the customer/prosumer.

1.1   Problem Statement

As a result of a growing social engagement and as society becomes increasingly more independent with regard to energy production and consumption, there is a need for a well-working local energy market. This local energy market shall intent to enable the community of a local energy system to trade their self-produced energy in an economical manner. As the implications of blockchain technology become more apparent, this technology might be the solution to the problem at hand. However, like the local energy markets this technology is still immature and thus there are numerous challenges that need to be overcome. To explore which actor should and how to facilitate a decentralised local energy market is the aim of this research.

1.2   Scientific & Societal Relevance

This research aims to provide the following scientific contributions. First, to establish the technical architecture and requirements that need to be met in order to facilitate a decentralised local energy market. Second, innovate business models for the actors considered to take upon the role of aggregator facilitating the local energy market. Third, an assessment of the business models by the use of a business model stress test. This assessment shall provide insight for decision makers regarding the vulnerabilities and robustness of the business models aiding them in the strategic planning of a potential business venture.

From a societal point of view, the development of this sustainable innovation is of importance. Especially considering the fact that most countries are lagging behind on development in this department from a political point of view. For example, the goals stated in the Paris-agreement regarding CO_2 emissions are likely to not be met (Detlef P. van Vuuren, 2016). However, there are over 300 local energy initiatives exemplifying that there indeed is a societal need and urge to be more environmentally friendly (Koirala and Oost, 2017). By creating these local energy markets, CO_2 emission shall be reduced and an incentive is created for others to join in this effort to become green and self-sustained. Lastly, the development of these social communities in today's society is something that should be applauded in my opinion. This combined with the possibility to extend towards charity models to help others around you is only beneficial to today's society.

1.3   Identifying the Knowledge Gap

The technology-push of popular new technologies like blockchains and IoT has accelerated the already changing energy domain. Combining this with the market-pull due to the growing societal need for self-generated and self-owned renewable energy provides us with a clear argument to focus the research in the field of decentralised local energy markets. The literature shows that there are many variables yet to be determined with regard to how these should be facilitated. Although the innovative technologies would theoretically combine the societal needs with economic benefits, the challenges like high invest-ment costs and reliable supply of energy within the local energy system, whilst maintaining the ICT

system are still to be overcome and there are no conclusive answers as to how the technologies could best be implemented. The identified knowledge gaps are therefore as follows:

- It is unclear what a local energy market technically requires.
- It is unclear how the blockchain can be used to implement a decentralised local energy market.
- It is unclear how the business model is to be innovated given the changing energy domain with regard to local energy markets.
- It is unclear what the robustness of the innovated business models is and where their weaknesses lie.

Providing answers to the knowledge gaps could lead to an accelerated implementation rate of local energy markets. This ideally should be done such that both the industry as well as the customers are benefited from the innovations. Furthermore, by stress testing the business models, it shall be made clear to which actor the aggregator role is best suited with regard to the local energy markets.

1.4 Research Objective

This research is focussed on identifying how local energy markets can be facilitated by the blockchain technology. This shall be done by researching the local energy system, the blockchain technology as well as incorporating the business science aspect of the industry. The aim is to identify the impact of the blockchain on the business models of the actors that are considered to take upon the aggregator role to facilitate local energy markets. This leads to the main research question that is stated in the following section.

1.4.1 Main Research-Question

'How does blockchain impact local energy markets business models?'

In order to structure the research and help answer the main research-question, there have been made sub-questions. These shall provide the necessary elements to finalise the research and answer the main research question.

1.4.2 Research Sub-Questions

SQ-1: 'What are the characteristics of local energy systems?'

By defining the local energy system and defining the context in which it is to be established is important for this research. It shall help to understand the place and function of the local energy market within this local system. Furthermore, by establishing the characteristics the initial requirements can be defined which shall help answer the following research questions.

SQ-2: 'What would be the key elements of local energy markets?'

Defining the key elements of the local energy market shall provide the requirements that need to be met in order to facilitate the local energy market. By providing these elements, the local energy market can be visualised and the first steps toward building a local energy market can be made. This identification will also allow for an analysis of the challenges that might come with facilitating local energy market.

SQ-3: 'What is the value proposition of the blockchain with regard to the energy industry?'

By researching the blockchain technology a basic understanding of the technologies potential can be formed. Furthermore, by examining the characteristics, the advantages and disadvantages of the technology can be mapped and the functionalities it can fulfil with regard to the local energy market can be established. This shall eventually lead to an overview of what value a blockchain can propose to the notion of local energy markets.

SQ-4: 'What are the uncertainties of using a blockchain to facilitate a local energy market?'

By synthesising the energy domain with the blockchain domain the step towards the identification of the uncertainties that come with the concept of decentralised local energy markets can be performed. This shall be done following the synthesis of the domains which are based on the literature review as well as a trend analysis of the current energy transition. Following the analysis the uncertainties can be established as well as two possible scenarios that are to be chosen on the extreme ends of the spectrum. These shall result in the heat map template that shall be used for the business model stress tests.

SQ-5: 'How may a blockchain facilitated local energy market be implemented in local energy systems?'

Considering the uncertainties that come with disruptive technologies like blockchain it is important to understand the various manners in which the decentralised local energy market can be implemented, and by whom. In order to assess this, there shall be provided a reference business model as well as innovated business models and value propositions. These shall provide an insight into how the relevant actors can capitalise on the potential of the decentralised local energy market.

SQ-6: 'How robust are the innovated local energy market business models?'

Via the use of a stress test the innovated business models are stress-tested against the uncertainties and scenarios that shall be identified from the literature. The business models shall be qualitatively assessed following the business model stress test methodology. The business model stress test shall highlight the vulnerabilities of the business model upon which improvements can be made following the analysis of the heat maps.

1.5   Research Outline

In this section the research outline is presented, this shall consist of a visual representation of the natural flow of the research based on the the research questions discussed in the previous section.

The research is built up out of five phases. First, the introduction phase which introduces the research and the methodology. Second, the information gathering phase which consists of Chapters 3 and 4 covering the energy industry, local energy domain and blockchain domain. Next, the synthesis is performed in 5. This consists of the establishment of the decentralised local energy market as well as an identification of the uncertainties following a trend analysis. This chapter are to provide the necessary information needed to perform the fourth phase. This phase is the analysis phase where the business models are innovated, stress tested and analysed. The fourth and last phase is the conclusion phase. Here the conclusions to the research are presented and discussed. Furthermore, this also consists of the recommendations for future work.

In Figure 1.1 the research outline is presented. This provides an overview of the natural flow of the research.
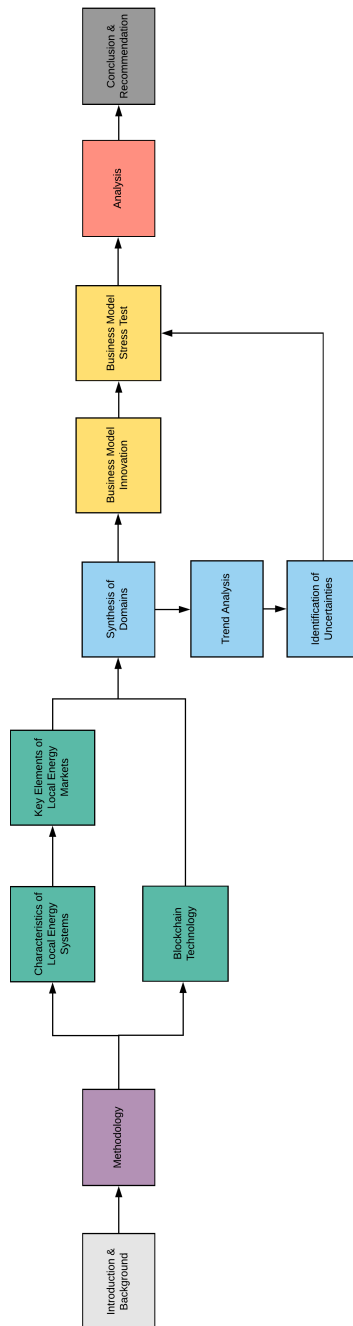
Figure 1.1: Research Flow Diagram

2 | Analytical Framework

This chapter shall provide the analytical framework that has been made use of for this research. The objective of the research is to provide a reference business model and innovated business models based on the emergence of the blockchain technology to the changing energy industry. These are to be stress tested to identify the weaknesses and help the actors to anticipate accordingly. This shall be done by following the business model stress test proposed by Bouwman et al. (2012). The business model stress test will allow them to assess the robustness of the business model and how and where to improve it. In the following section first, the business model ontology shall be provided after which the business model stress test shall be further elaborated upon. Last, the research methods shall be discussed.

2.1 Business Model Ontology

In recent years the business model has surged as a concept widely accepted to aid in developing sustainable businesses or business ventures. Shafer et al. (2005) stresses the power of business models and separates the concept of business models from strategy. This is important to note with regard to this study that there shall be a focus on the concept of business models which lead to recommendations and insight to decision/strategy makers. The concept of the business model can be used to build a blueprint that will help to understand your business and is intended to design, implement, operate, change and control their business (Johnson, 2010), (Wirtz et al., 2010). Business models are traditionally formed around three key elements. These are the notion of value proposition, value creation and value capture (Zott et al., 2011). These respectively entail the drivers of customer value and the unique offerings of the firm, the actions that increase the worth of the goods and/or services and thus essentially the business and last, the underlying cost structure and revenue value that is used to determine the profitability and economic sustainability (Osterwalder et al., 2014), (Chesbrough and Rosenbloom, 2002). Following these elements, the business model of the industry shall be examined and the foundation is built that is needed to provide an innovation towards a business model that is optimised for the effective usage of the new technologies. As the technological innovations are adopted by the industry and consumers, the business models should innovate to ensure the business to keep creating and capturing value (Chesbrough and Rosenbloom, 2002). Moreover, the innovation of the business model itself is able to create value as well, and thus must not be disregarded (Amit and Zott, 2012). However, the fact that business models are often used as a unit of analysis there are many different opinions on what factors to implement and to what extent these are of importance or applicable to the industry. This has led to a number of different approaches of which three shall be highlighted in the upcoming sections.

2.1.1 Business Model Innovation

In Schumpeter (2010) the foundation to most of today's definitions of innovations was laid. He explained innovation as 'new combinations' and more detailed: 'an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening up a new source of supply of materials or a new outlet for products, by reorganizing an industry and so on'. This still shows in today's definitions of innovation and bringing this point of view towards business models thus leads us to a definition proposed in Heikkilä et al. (2016), which is as follows: 'Business model innovation is the innovation in company's business model that is new to the firm and results in observable changes in

the firm's practices towards its customers and partners.'

Much like technology, products and processes, the business model is thus subject to innovation as well. In order to grow with the market or to gain competitive advantage, value shall have to be created. In recent years business model innovation has been increasingly considered as a source of value creation, as it potentially provides a sustainable competitive advantage.(Zott et al., 2011)

To conclude, the business model as the unit of analysis used as a means to create value is considered to be of great importance to this research. Therefore, in the following sections some common approaches of business model creation are discussed.

2.1.2   Business Model Canvas

First introduced by Osterwalder and Pigneur (2010), the Business Model Canvas (BMC) is a single reference framework that allows businesses to visualise their business model (BM). The canvas consists of 9 blocks capturing a wide range of aspects that are considered to be of great importance for the business. First, the customer segment represents the separate customers into different groups that profitable for the business. It helps the business to identify what customers it wants to reach. Second, the value proposition is the collection of products and services a business offers to meet the needs of its customers (Osterwalder and Pigneur, 2010). Third, the channels are identified, these represent how the company reaches the identified customers to deliver their value proposition. Fourth, the customer relationship is a description of the type of relationship the customer has with the company. Fifth, the revenue streams identifies how the companies profit from its customers. Sixth, the key resources, is a description of what the most important assets of the company are. These are categorised in Physical (e.g. buildings and equipment), Intellectual (e.g. customer data and copyrights), Human (e.g. skilled workers) and Financial (e.g. cash) Resources. Seventh, the key activities entails what the companies most important activities/actions are in executing the companies value proposition. Eighth, the key partners are those who allow the company to offer its value proposition and perform al its activities. (eg. partnerships). Ninth, the cost structure consists of the most important costs resulting from running the company (Osterwalder and Pigneur, 2010). The BMC template is provided in Figure 2.1.
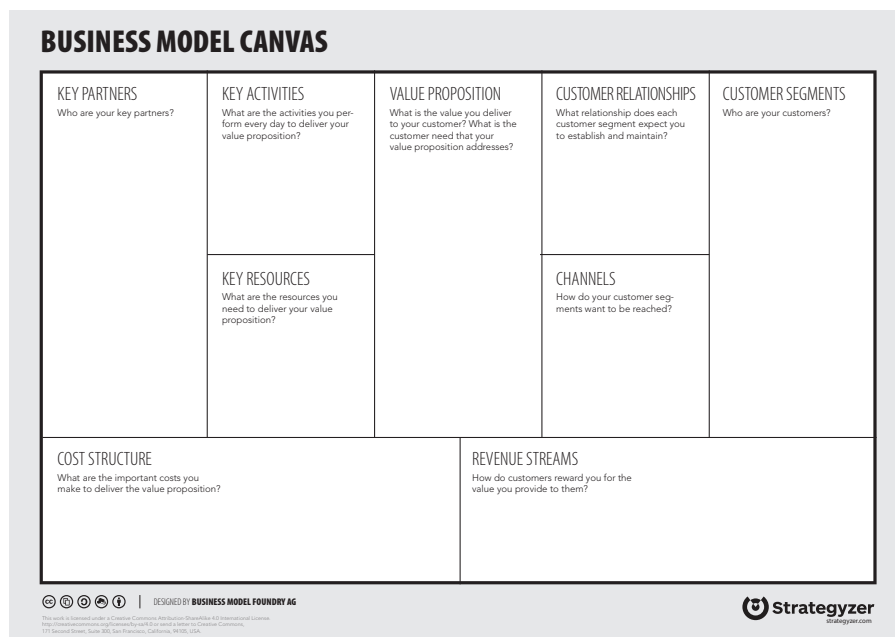
Figure 2.1: Business Model Canvas Template

The main advantages of the BMC are in the generic nature of the canvas. It easily allows decision makers to experiment with different kinds of business models. A disadvantage the BMC has is that it does not allow the business to be placed within the context of the industry it is in.

2.1.3 STOF Model

First introduced by Bouwman et al. (2008), the STOF model consists of four domains: the Service, Technology, Organization and Finance (STOF), and was developed in the context of service design. It is however argued by the authors that the model can be used in other fields of study as well. Elaborating on the domains: the service domain focusses on delivering value to end-customers. The technology domain focusses on technological functionality, infrastructure architecture and elements. The organisation domain focusses on the internal and external processes of the organisation. Internal processes refer to things like resource management and allocation where the external processes refer to collaboration within the network of the business. Lastly, the finance domain focusses on the revenue models and investments. In Figure 2.2 the visual representation is provided.
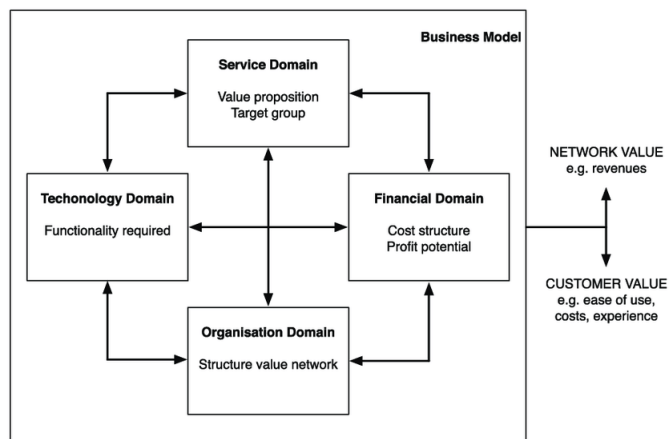
Figure 2.2: STOF Model Template

The advantage of the STOF model mainly lies within the more elaborate nature in comparison to the BMC. This, however, can also be regarded as a disadvantage as it requires a complex analysis to establish a business model.

2.1.4 CSOFT Model

Heikkila et al. (2005) propose a business model ontology closely related to the STOF model discussed in the previous section. However, in addition to the four domains, the customer relationship is added. Which in this model is a central element. Furthermore, the domains are interpreted differently. Here the Service domain is the element that creates value for the customer, Organisation of Network defines the roles and responsibilities within the network, Finance focuses on the costs and revenue and Technology refers to the ICT support of the services. Lastly, the Customer Relationship domain focuses on the jointly owned long-term relationship with the customers. In Figure 2.3 the visual representation of the model is provided.

The advantage of the CSOFT model mainly lies within the fact that it encapsulates most of the STOF Model but adds the customer relationship domain. A disadvantage of the model is the focus on customer relationship with technology as a support domain. This makes the model very network-based and less well-rounded.
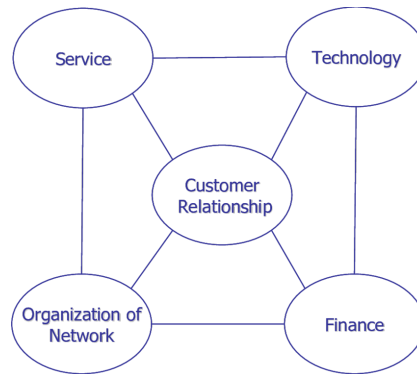
Figure 2.3: CSOFT Model Template

2.1.5   Value Proposition Canvas

In order to further elaborate on the BMC one can choose to make use of the value proposition canvas (VPC), which was first introduced by Osterwalder et al. (2014). The VPC uses the Customer Segment and the Value Proposition blocks of the BMC to really understand what the customer wants and how the value proposition can be fitted to their needs. The right half of the canvas is thus of an observing nature. The VPC is built up as follows. First, the persona is detailed. Followed by a description of what it is that he/she wants to get done. The pains and gains are listed and represent what annoy or trouble the persona and what would make them happy respectively. Next, the left half of the canvas can be designed. First, one describes exactly what the products and/or services are and upon what the value proposition is built. Next, the pain relievers, which is directed towards the pains of the persona, are listed. This is then followed by the gain creators which in turn are directed towards the gains of the persona. If done right, this will create a fit between the two sides. A strong fit implies a solid value proposition. The VPC template is provided in Figure 2.1.
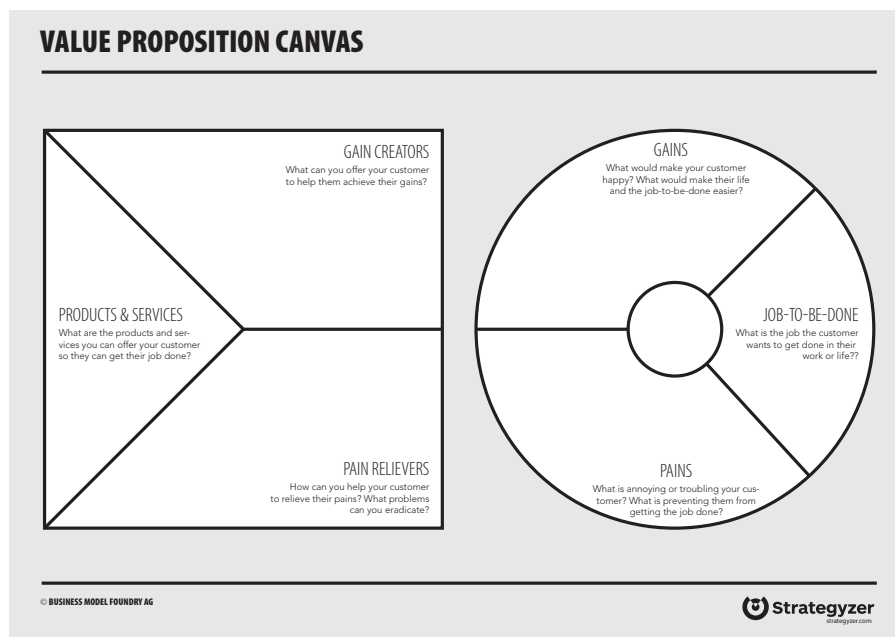
Figure 2.4: Value Proposition Canvas Template

2.1.6 Conclusion

To help evaluate what business model ontology is to be used, Table 2.1 is provided. This provides an overview of the considered business model ontologies and the criteria used to base the business model ontology decision on. This has resulted in the decision to select the BMC in combination with the VPC. This was done for the following reasons.

First, the BMC approach was chosen due to the fact that the notion of decentralised local energy markets as well as the blockchain technology itself is still in its infancy. The applications and implications of the technology are unclear and it is therefore highly likely that the models are subject to change over time. This therefore requires the need for multiple business models to be proposed. The role of the aggregator can be taken upon by multiple actors and shall all implicate varieties in the business models. Second, the requirements of the STOF and CSOFT models require an in-depth analysis that is deemed unnecessary with regards to the scope of this research. To negate some of the disadvantages of the BMC there shall also be provided VPCs. These shall help place the BMCs in the context of the local energy domain. It will furthermore allow the value proposition component of the business model to be further elaborated and shall make the value capture in the later stages of the business model application easier. Third, this model is best suited for strategic considerations done by managers and decision makers in the future due to its relative simplicity and visual nature. In Chapter 6 the innovated BMCs and VPCs shall be provided and elaborated upon.

Table 2.1: Overview of Business Model Ontology

Model	Industry	Strengths	Weaknesses
Business Model Canvas	Generic	Well-Known, Low Complexity, Strategic Analysis	Limited complexity captured
Value Proposition Canvas	Generic	Customer Focused, Complementary to the BMC	Lesser-Known
STOF Model	ICT Services	Detailed analysis and description of design variables	Lesser-Known, Complex
CSOFT Model	Networked Business Models	Detailed analysis and description of variables, Customer Relationship centred	Lesser-Known, Complex, Less Well-Rounded

2.2 Business Model Stress Test

This section shall first elaborate upon the the business model stress testing tool proposed by Bouwman et al. (2012). The tool is was proposed to test the long-term robustness of the business model. Intending to test the feasibility as well as the viability of the business models against the changing environment (i.e. the transitioning energy landscape). In the following subsections the six steps that make up the tool are discussed.

2.2.1 1. Selection and description of Business Model

The first step is to select an approach to describe the business model. This can be done via any method as long as it consists of enough richness. Examples are the afore-discussed business model canvas and STOF.

2.2.2 2. Selection of uncertainties

An essential and difficult task. The conclusions drawn from the stress test are highly affected by the uncertainties selected in this process. It is therefore important to properly select a limited number of

uncertainties to make the stress test manageable. Uncertainties can be selected based upon literature, scenarios or domain experts.

2.2.3   3. Mapping of BM to uncertainties

During this step the uncertainties are mapped against the components of the BM. Described in facts and identified issues. By mapping the uncertainties to the different components of the business model a clear overview can be established of how uncertainties relate to the business model. These can then specified into outcomes.

2.2.4   4. Heat Signature

In this map a heat map is prepared and shall make use of the colour scheme presented in Figure 2.5. Following this heat map the stress-test can be performed. This determines the possible impact of the future on the business models.

Red	Red: Possible showstopper: needs attention from a strategy perspective
Yellow	Yellow: Negative (or positive) effects cannot be excluded, but attention is required
Green	Green: No negative effects are expected
Grey	Grey: No relevant influence

Figure 2.5: Colour Scheme

2.2.5   5. Analysis

This step is centred around the analysis of the heat signature. The analysis is focussed on gaining insight into the weaknesses of the business models. The test provides firstly the colour coding and second grounding. This thus shows why certain choices cause problems and how this insight can be used to make a more robust business model. First, a sub-view analysis shall be performed on both the business model components as well as the uncertainties and their scenarios. Next, a pattern analysis shall be performed to identify whether there are preferred uncertainty outcomes or to identify possible outcomes that would imply the BM not to function at all. Last, a cross-comparison shall be performed to rank the business models following the previous findings.

2.2.6   6. Actions & Improvements

This step revolves around interpreting the insight into the robustness and vulnerable parts of the BM. Typically, recommendations are provided that address the weak parts in the BM, or are aimed at improving consistency.

2.2.7   Conclusion

In Table 2.2 the steps that shall need to be taken in this research are depicted. These are furthermore accompanied by the data sources that shall be drawn upon and the output of the step. This chapter has already provided the selection of the business model approach. However, in order to provide the business models, first there shall have to be done a literature review to establish the domain in which the local energy market is to be facilitated. As well as the technical requirements that the system needs to fulfil. In Chapters 3, 3.3, 4 and 5 these are discussed.

Table 2.2: Business Model Stress Testing

Step	Data Source(s)	Output
Selection & Description of Business Model	Desk research	Reference business model, innovated business models
Selection of uncertainties	Desk research Secondary Data	Selection and description of most important uncertainties
Mapping of uncertainties	Desk research	A clear overview of how the uncertainties relate to the business model components
Heat signature	Desk research, Experts in the field	Heat map, description of the impact of the uncertainties to the business model components
Analysis	Heat map	Insight into the weaknesses of the business model
Conclusion	Heat map	Recommendations addressing the weak points to improve the business model

2.3 Elaboration on Research Methods

This section shall elaborate on the manner in which the data shall be gathered to perform the six steps presented in Table 2.2. This shall consist of an elaboration on the characteristics, limitations and discussion of the specific research methods.

2.3.1 Literature Review & Desk Research

In order to gain a better understanding of the transitioning energy industry a preliminary analysis shall be performed. Within this domain business models were chosen as the unit of analysis. Further research on business models led to the selection of three business model ontologies and finally the selection of the business model canvas and the value proposition canvas. This selection was based on extensive literature studies performed using scientific databases such as Google Scholar and Scopus.

By performing an elaborate study of academic literature and desk research, relevant literature was selected for both the local energy domain as the blockchain domain. This was done to identify the key characteristics and elements of local energy systems and blockchain technology. This helps to understand how blockchain could be used to facilitate local energy markets. Additionally, it allows us to better assess the impact of blockchain technology on the uncertainties that need to be identified. As a result of the literature study, there will furthermore be compiled business models for the considered actors.

As a result of the immature nature of the blockchain technology, there was required a slightly different approach than for the energy domain. In addition to the limited amount of scientific literature, there was made use of expert blogs and company websites. In the following, the types of documents are listed:

1. Scientific literature consisting of for instance books, journal papers, articles and others.

2. Grey literature (e.g. company and government reports)

3. Blogs

4. Company & Institution Websites

2.3.2   Secondary Data

Secondary data refers to data gathered by someone other than the researcher conducting the research. In this research, the selection of secondary data consists of the trend analyses used to find the uncertainties that together with business components make up the heat maps. Regarding the trend analyses, there are two options to choose from. First, to derive a list of trends via popular methods such as interviews, workshops, STEEP analyses or brainstorming sessions (Bradfield et al., 2005). Second, secondary data can be made use of. This can be retrieved via external databases or survey of literature. Regarding this research, the latter option was opted due the discovery of relevant trend analyses and inefficiency of performing new trend analyses. In Section 5.5 these shall be presented and discussed.

2.3.3   Questionnaire

A questionnaire was made to collect data of experts in the field to quantify the qualitative perception of the individuals. In order to minimise the bias and subjectivity of the results, the data shall preferably have to be acquired from different perspectives, enterprises and expertises (Verschuren et al., 2010). This thus required the identification of individuals with knowledge of the blockchain, energy industry and local energy markets preferably working in different roles rather than the selection of a random sample (Sekaran and Bougie, 2013). A total of 40 experts was selected on the basis of their expertise shown through an analysis of the existing literature on local energy markets. To maintain validity, the questionnaire was limited to participants with knowledge in these field. By adding the questionnaire a quantitative approach is added to the qualitative approach of the research. In Table 2.3 the questionnaire participation list is provided.(Yin, 2003)

Once the questionnaire data was collected it was processed via the use of an MS Excel document. This document contained the results of the data per individual as well as the average total score per question. The score of the answer was rated on an ordinal scale where a 1 was given to the answer: 'No negative effects are expected', a 2 to the answer: 'Negative (or positive) effects cannot be excluded, but attention is required', and the highest score of 3 was given for the answer: 'Possible showstopper: needs attention from a strategy perspective'. As the scale used for the questionnaire is equal to the scale used for the stress test there shall have to be made no adjustments. To provide the heat signature of the Prosumer the Key Partners component was taken out of the heat map. Furthermore, a conservative safety factor of 1.1 was applied based on an estimation of the competitiveness and willingness of Sajn (2016), Masera and Couture (2015), Facchinetti et al. (2016) and Wilson Rickerson and Crowe (2016).

Table 2.3: Questionnaire Participation List

Function	*Expertise*
Assistant Professor	Sharing Economy, Peer-to-Peer Platforms
Assistant Professor	Electrical Energy Systems
Associate Professor	Renewable Energy, Electricity Market Design
Senior Research Fellow	Energy Market Developments
	Strategic and tactical consultancy in the energy & utilities industry
Post-Doctoral Researcher	Community Energy Systems
Researcher/Engineer	Business models for decentralized energy markets, Analysis & design of local energy markets, Analysis of blockchain technology as information systems for energy markets

2.3.4 Research Validity

The research validity reflects on the ability of the research to safeguard the construct, internal, external validity as well as the reliability.(Yin, 2003)

First, the construct validity of the research is largely safeguarded via the use of triangulation, as the research draws upon data gathered from literature, secondary data and the questionnaire. Second, the internal validity relates to establishing causal relationships. To counter the fact that the business model stress test is the only method that establishes the robustness of business models, this research lays a theory and literature based foundation. Third and fourth, the external validity is mainly focused on theoretical replication as this research is highly focused around the local energy domain, blockchain technology and business models as a unit of analysis. However, it is debatable too what extent the findings of this research are replicable or generalisable with the low number of participants. The aforementioned concepts are furthermore discussed in Section 8.2.2.

3 | The Energy Domain

This chapter shall focus on answering the first two sub-research questions by providing background information to the energy industry, establishing the local energy system and local energy market. After establishing an understanding of the energy industry, the local energy system shall be described and proposed. Last, the local energy market shall be defined and designed for all of its respective elements.

3.1 The Changing Energy Landscape

As the energy domain is currently in a state of transition due to among others the development towards the smart grid, emergence of Electric Vehicles (EV) and the penetration of Distributed Energy Resources (DERs). It is important to provide some background information to the current energy system as well as providing some insight into the most prominent innovations driving the transition. This section shall thus focus on establishing how the energy industry currently works, what transitions and innovations there are taking place.

First, some background information on the current energy system is provided in Section 3.1.1. This section covers both the structure, involved actors and market mechanism of the current energy system. Second, in Section 3.1.2 some phenomenon and innovations impacting the transition towards the future energy domain are provided.

3.1.1 The Current Energy System

The energy system is primarily designed to supply the end-users with energy and energy services. In order to make the system more efficient, there has been created a liberated market by the government. This forces the actors to be competitive with each other. Such that due to the competitive nature of the system the customer is benefited.

The system starts with the generation of energy by the supplier. The generated energy is then brought to households via first the Transmission System Operator (TSO) and second the Distribution System Operators (DSOs). The TSO is an entity, in the Netherlands this is TenneT, that is responsible for the transmission of electrical power and is in charge of balancing the supply and demand of energy in the grid (de Vries, 2017a). The DSOs are those responsible for operating, maintaining and development of the distribution system in a given area (Kaeding, 2011). To illustrate, in Figure 3.1 a simplified representation is depicted.

As the TSO and DSOs have been made responsible for the stability of the energy infrastructure and as the production of electricity is subject to the demand of the grid and thus is only produced at the moment that it is demanded. There has been made a market mechanism to deal with these inherent difficulties. In Section 3.1.1 this shall be further elaborated upon.
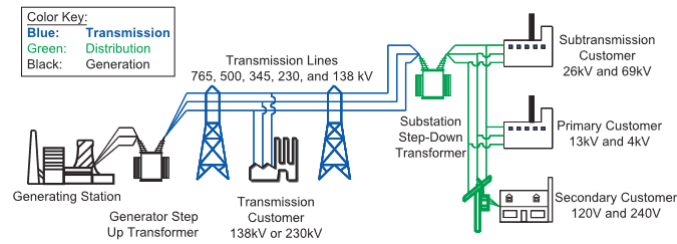
Figure 3.1: Simplified Structure of the Electric System retrieved from Force (2004)

Current Market Mechanism

Resulting from the fact that energy is not produced beforehand, the power exchange market makes use of a two-sided auction. Consisting on one side producers who want to sell and on the other side consumers who want to buy. This auction works with a single price for all accepted bids. To elaborate, producers bidding lower than the market price will receive the market price and consumers bidding higher than the market price will pay the market price. This incentivises them to bid the minimum price needed to operate the power plant and to bid the maximum for both respective parties. This mechanism ensures economic efficiency, resulting in the cheapest power plant being run and consumers that are in need of electricity the most being served. Examples of electricity markets are Nordpool, EEX and Powernext.(de Vries, 2017b)

As a result, market mechanism shortages are naturally mitigated. This is due to the fact that if the price of energy increases the demand should go down. However, due to a high willingness to pay of the consumer and no information or response options, the price-elasticity of demand is currently very low. This might result in situations where demand needs to be curtailed during shortages resulting in a failure to reach equilibrium in the market (de Vries, 2017a).

As mentioned, the DSO is responsible for the balancing of generation and consumption. However, trade always takes place before the demand, based on forecasts, and thus contracts are never fully accurate. This leads to an imbalance. This imbalance can in turn result in, for instance, uncontrolled black-outs and frequency disruptions. To counter this imbalance there are Balance Responsible Parties (BRP), these are allowed to inject or withdraw electricity into or from the transmission network. This is done in collaboration with the TSO (de Vries, 2017a).

Energy Value Chain

Considering the background information provided in Section 3.1.1 and 3.1.2 and analysing the current value chain presented in Figure 3.2 we find that the energy system consists of four processes: power generation, power transmission, power distribution and power consumption. The energy value chain provides the logical flow where the energy producers first generate electricity followed by the TSO transmitting it through the grid, the DSO distributing it to the households and the households consuming the electricity.
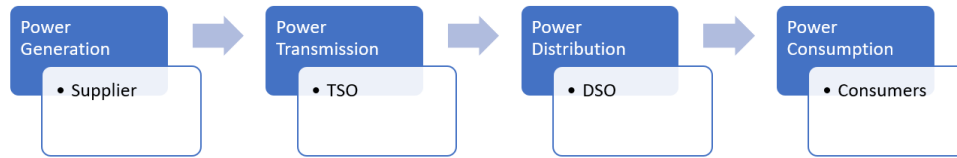
Figure 3.2: Electricity Industry Value Chain Adapted from Richter (2012)

3.1.2 The Innovations in the Future Energy Domain

Where the current energy system works one-way (from supplier to consumer), with emergence of technologies like the IoT soon this will likely not be the case any more. These innovation provide a possibility towards a smart grid which has the potential to change the energy landscape dramatically. Gharavi and Ghafurian (2011) defined the smart grid as 'an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across the entire spectrum of the energy system from the generation to the end points of consumption of the electricity'. This thus means that there is both information send to the supplier as well as to the customer. The current grid is not yet build in such a manner however, current technology does allow for a bi-directional communication between consumer and supplier. Implementing IoT would allows users to for instance see when energy is expensive or cheap and thus they can choose to postpone certain actions like washing your clothes. This saves money for the consumer but also makes it such that the peaks in energy will be lower and thus black-outs and other problems are less likely to occur. In the future this will likely all be done automatically and as a result a more reliable, efficient and available industry is created. It must be noted that here, like in many other innovations nowadays, the privacy is at stake.

To be able to fully provide these services the smart grid requires three things. A data infrastructure, a layer that allows for financial transactions and a(n) (IoT) control architecture. This data infrastructure ideally could be used by mutually competing and distrustful entities. As this infrastructure needs to ensure integrity, authenticity, commercial secrecy and customer privacy. The financial layer on the smart grid should eliminate or minimise transaction costs and support innovation of product and services. Lastly, the smart grid should allow for a(n) (IoT) control architecture such that it allows for Application Programming Interface (API) and supports, for instance, an ecosystem of smart controls. With regard to this smart grid the blockchain technology is the most promising technology able to provide the financial transaction layer and the (IoT) control architecture (Shipworth, 2017).

As the energy domain shall increasingly produce more green energy generated by Distributed Energy Resources (DERs) and prosumers, there will also be an increased risk with regard to the reliability of the system. As these intermittent power sources bring forth issues like power harmonics there shall have to be made use of energy storages and active network management systems. This thus brings a demand for flexibility in the industry.

Describing the Prosumer

The term 'Prosumer' is a contraction of consumer and producer. However, the concept of a prosumer is not just a consumer that has started to produce his/hers own energy. As researched by Olkkonen et al. (2017) and Lavrijssen and Carrillo Parra (2017) there are many different views in the literature with regard to the term prosumer. These vary from the aforementioned one to a very technical approach where the prosumer is not the person but the actual device generating energy is considered a prosumer. Therefore it is important to define and describe what the term prosumer entails in this study. For this research the following description was chosen as it most suits the intent of this study. The notion of a

prosumer entails someone that is: engaged in the market, and thus is considered to be an active agent, directly or indirectly (Bremdal, 2011). Due to the development of the smart grid these prosumers shall be provided an economical incentive motivating them to (Rodríguez-Molina et al., 2014):

- Produce energy

- Store energy

- Engage in economical and technological optimisation

- Engage in the creation of value for electricity services

As a result of this development, the prosumer shall disrupt the energy value chain. This shall be further discussed in Section 6.1.

Microgrids

A microgrid refers to a local grouping of households that generate and consume their self-produced energy, households that solely consume energy, distributed energy sources like wind turbines and energy storages (Hatziargyriou, 2014a). There are two main microgrid set-ups. First, a grid-integrated microgrid, meaning there is a point of coupling to the traditional power grid. Second, a grid-defected microgrid, meaning there is no point of coupling to the traditional power grid. In the first scenario, the microgrid is still capable of drawing power from the traditional grid making up for a lack of self-generated energy. Furthermore, they are able to give back excess energy into the traditional power grid. In scenario two this is not the case and thus these microgrids need to have significantly more energy storage (Fang et al., 2012). Figure 3.3 provides a visual representation of a grid-integrated microgrid with both loads and generation. A grid-defected microgrid would in this figure not have the connection to the utility grid.
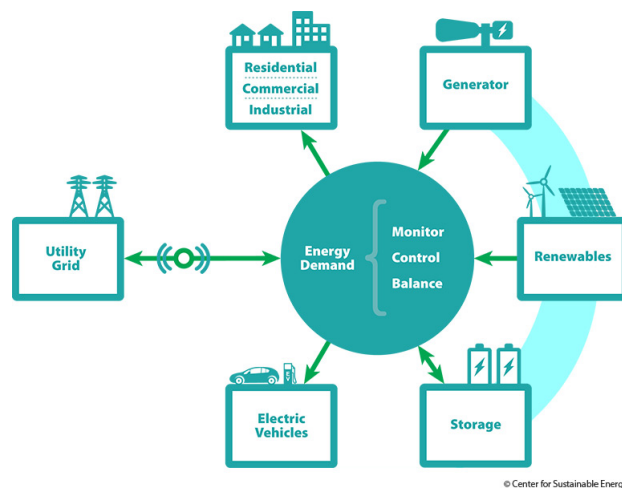
Figure 3.3: Visual Representation of a Microgrid retrieved from Center (2018)

The key characteristics that can be derived from microgrids are considered to be the focus on local generation, two operation states, active operation and multiple scales. Two operation states refers to the ability to have the capability of handling both a grid-connected state as well as an emergency state (which does not apply for grid-defected microgrids) in which it is grid-defected. The active operation refers to the management and coordination of the available sources present in the microgrid. Lastly, the multiple scales refers to the fact that microgrids are implementable in multiple scales. From a small scale of just a couple houses to a complete campus. Due to these characteristics microgrids have

some notable advantages. Microgrids potentially are more resilient (especially in the presence of a well-working energy storage system), more efficient, more environmentally friendly, more flexible, easier to control and microgrids are more modular.(Hatziargyriou, 2014b)

Virtual Power Plants

According to Hatziargyriou (2014a), a Virtual Power Plant (VPP) is 'a cluster of DERs that are collectively operated by a central control system'. Thus, a VPP can replace a conventional power plant whilst providing more flexibility and efficiency. The concept of virtual power plants (VPPs) furthermore aims to counter over-capacity due to low-visibility of DERs (Pudjianto et al., 2007a). This concept would provide possible solutions to the inherent challenges of microgrids like reliability. The differences between microgrids and VPPs are mostly apparent in the locality and the size of the installed capacity. In microgrids, the DERs are located within the local distribution network and are intended to solely satisfy local demand. In contrast, DERs in VPPs are not necessarily located in the same network and often participates in the conventional markets as well.

3.1.3 Integrated Community Energy Systems

Another phenomenon, more closely related to local energy markets, in the process of the movement towards sustainable self-produced and self-owned energy are Integrated Community Energy Systems (ICESs). An ICES is, 'a multi-faceted approach for supplying a local community with its energy requirement from high-efficiency co-generation or tri-generation, as well as from renewable energy technologies coupled with innovative energy storage solutions including electric vehicles and energy efficient demand-side measures', as defined by Mendes et al. (2011).

The successful implementation of an ICES has the potential to lower the emission of greenhouse gases, ensure financial benefits for the local residents, contribute to the penetration of renewable energy and thus enhance the quality of life (Harcourt et al., 2012), (Koirala, 2017). However, the actual value of such a system to the community as well as to the entire energy system is yet to be determined (Koirala et al., 2016a). Furthermore, there are a plethora of barriers and challenges with regard to ICESs. These vary from challenges in the institutional organisations, grid connection issues, capital costs and more as stated by Swider et al. (2008).

With regard to the costs involved with implementing an ICESs there can be made the distinction between grid-defected and grid-integrated, as mentioned in Section 3.1.2. As researched by Koirala (2017) an grid-defected ICES is currently economically infeasible. Koirala (2017) stated, 'With regard to grid-integrated systems the benefits are highly subjected to system of prices and charges as well as institutional settings available for their operation.'. Moreover, as researched in Hittinger and Siddiqui (2017) the benefits with regards to the emission are non-existing.

3.1.4 The Reference Business Model Canvas

In the following the business model of the smart grid shall be provided. This was compiled as a result of the findings gathered from the reviewed literature. This shall function as a reference to the business models that shall be provided in Chapter 6. The business model canvas is presented in Figure 3.4.
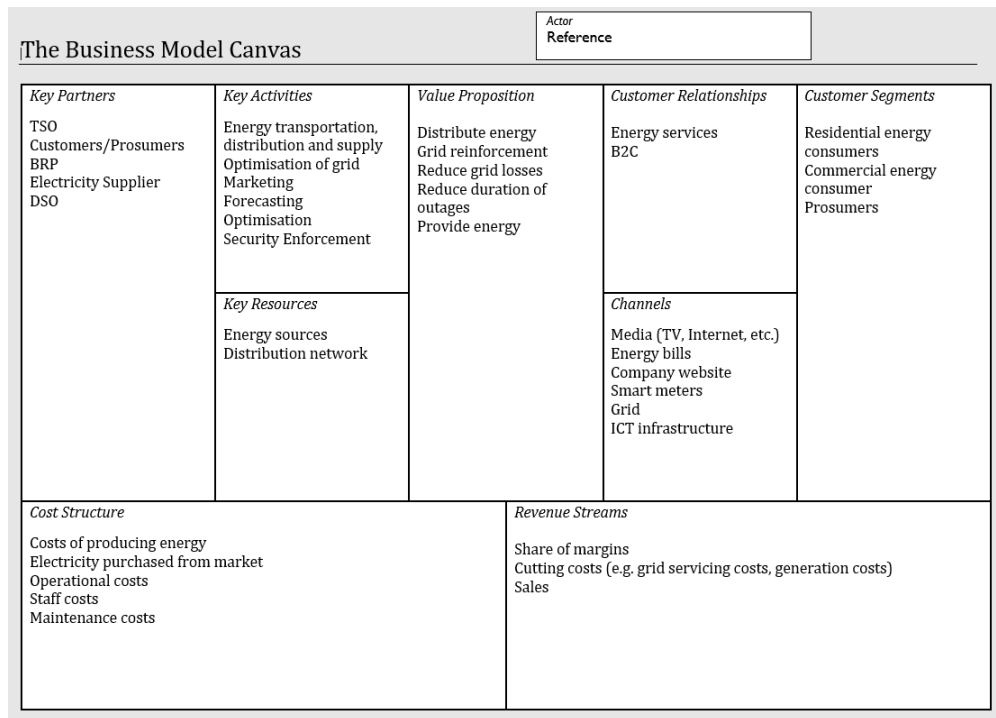
Figure 3.4: Reference Business Model Canvas

The canvas visualises the most important components that are relevant to the energy industry. Notable components here are: the Value proposition and Key activities. These exemplify how the activities are largely focussed around the optimisation of the grid and how much of the value proposition is dependent upon these activities. Furthermore, one can see how significant the implementation of the IoT as an integral part of the smart grid is.

3.1.5 Conclusion

The previous sections have provided insight into the current energy industry and the transitions that are currently taking place. As the consumer/prosumer shall play a more central role in the future energy domain it is important to aid them in their desire to trade self-generated energy. Therefore, in the following sections, the local energy domain shall be further explored. More specifically, the local energy system and market. This due to the fact that a successful implementation would benefit not only the traditional actors of the energy industry, but also the increasing pool of consumers turned prosumers demanding to be empowered. How this local energy market is to be facilitated, by whom, where the opportunities and weaknesses lie is however still to be determined. In the following section therefore these chapters shall be attempted to be answered.

3.2 Local Energy Systems

This section shall focus on identifying and exploring Local Energy Systems (LESs). This shall be done to answer the first research sub-question namely, 'What are the characteristics of local energy systems?'. The local energy system shall first be defined followed by an identification of the characteristics. This in order to provide the requirements needed to conceptualise the local energy market (LEM), that is yet to be researched, and its place and function within the future energy domain. This to provide a basis upon which the LEM can be built.

3.2.1 Defining the Local Energy System

The current grid works in a top-down architecture supplying the households and/or communities via a centralised energy system. The notion of local energy systems is however built upon the idea of a bottom-up architecture redesigning the current energy system. The intention of the local energy system is however geographically constraint to the community of participants and thus this approach is limited to this vicinity. The smart grid shall likely be a combination of largely the original top-down architecture in a smart grid configuration and a niche market for bottom-up initiatives like the local energy system. The bottom-up architecture allows communities to take control over their energy generation and the local energy system itself, empowering its members. Therefore we define the local energy system as: an agglomeration of households and/or small enterprises within a geographically constraint area built from a bottom-up approach.

3.2.2 Organised Prosumer Market Model

This section shall focus on establishing what the place of the LES is within the smart grid. This shall be done following the work of Parag and Sovacool (2016). In Figure 3.5 the organised prosumer group model has been adapted to provide a proposed LES. In the original organised prosumer group model the grid consists of organised prosumer groups that form separate local energy systems making up the grid from a bottom-up approach each technically functioning as a virtual power plant to the smart grid, something that has been proven to be feasible by Pudjianto et al. (2007b). This would allow the local energy system to be used as a tool for demand-response (Shariatzadeh et al., 2015). Although the adapted approach allows for the same flexibility services it must be noted that the LES is to be designed as a niche market and thus shall not nearly serve as many customers as the other model. However, the exact pool of customer the local energy systems are to serve is to be determined and thus the impact is hard to predict. This model is furthermore not per se the envisioned structure of the entire grid but would provide opportunities to local organisations and neighbourhoods that demand more from the grid. Besides allowing the communities to generate revenue due to their self-generated resources for the benefits of the community, this prosumer group model would relieve the grid from peak loads and other issues like it (Pudjianto et al., 2007a). Furthermore, theoretically this model could allow for aggregators to emerge however this for now is disregarded but shall later be added and discussed in Section 6.1.1.
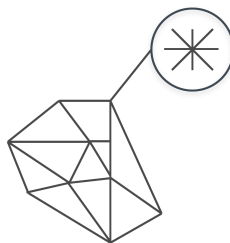
Figure 3.5: Organised Prosumer Group Model adapted from (Parag and Sovacool, 2016)

3.2.3   Characteristics of Local Energy Systems

This section shall focus on establishing the characteristics of the local energy system. Generally, a microgrid is considered to consist of five distinct layers. These shall thus be considered for the organised prosumer group local energy system as well and are as follows (Martin-Martínez et al., 2016)(Bauer, 2017):

1. Physical Infrastructure and Local Sources

2. Communication Layer

3. Control and Protection Layer

4. Business Models

5. Regulatory Framework

To elaborate, the physical infrastructure and local sources refer to the manner in which a microgrid is built in terms of electrical components. Second, the communication layer refers to the (international) standards used to facilitate communication. Third, the control and protection layer covers the manner in which quality, optimisation and reliability are ensured. Fourth, Business Models concerns the business approach to the LES. Fifth, regulatory framework covers topics like ownership and aggregation.

The physical infrastructure and communication layer are outside of the scope of this research and shall therefore not be discussed in this research. This section shall mainly focus on the control and protection layer where the business models are to be discussed in Chapter 6. Detailing the control layer, there are three levels namely, local control, internal control and an upstream interface which at this point can be viewed upon holistically due to the defined scope of the research (Hatziargyriou, 2014b). The aforementioned components are therefore simplified as follows and shall be elaborated upon in the following:

- Distributed Energy Resources

- Energy Consumption

- Energy Control System

Distributed Energy Resources

Ackermann et al. (2001) provide a take on the definition of Distributed Energy Resources (DERs). This research shall loosely base the DERs definition on this work and shall define DERs as: devices that provide electrical generation like solar panels and wind turbines, as well as electrical storage. DERs can thus be distributed into two groups: distributed generators and storage systems. First, the distributed generators are to be discussed.

Despite the fact that distributed generators like solar panels and wind turbines are currently able to produce sufficient energy at a competitive price (Andrei Ilas and Taylor, 2017). The inherent problems of these intermittent energy sources still remain. One example of this is the fact that microgrids that heavily or solely reliance on variable generation of energy are prone to blackouts during peak loads. Moreover, spatial distribution and zero to low levels of inertia are issues that especially microgrids have to deal with. Due to the increasing penetration of Renewable Energy Sources (RESs) and growing energy consumption, these are considered to be the main concerns regarding a reliable (local) energy system.(Alanne and Saari, 2006)

Most of the aforementioned problems are due to the fact that DERs are, as mentioned, intermittent in nature. This implies that the implementation of an energy storage system is essential to the LES, and

even more so if the LES is to facilitate a LEM as argued by Palizban et al. (2015) and Lüth et al. (2018). In terms of economic feasibility energy storage systems have been one of the main obstacles, as they traditionally have been expensive due to the high cost of batteries and installation. However, in recent years the price of batteries has dropped significantly (Aaron Denman and Shen, 2017). This drop is among others a result of the economy of scale, PVs that are put back onto the market due to no longer being able to be used for its initial intended purposes (e.g. batteries of electric vehicles (Stapczynski, 2018)) and technological improvements in the industry. Furthermore, promising innovations regarding the usage of Electrical Vehicles (EVs) for energy storage are being researched and might turn out to be viable options as well (Stapczynski, 2018).

The intermittent nature of DERs and thus the issues with regard to reliability could prove to be of importance with regard to the LEM, as logically the system shall need to be supplied with a reliable energy source to facilitate the local market. Moreover, new technologies like the blockchain that shall potentially enable these markets are notorious for their high energy consumption. Furthermore, the blockchain itself has reliability issues due to the limited scalability of the system which shall be further discussed in Chapter 5. This thus implies that the scaling of the local energy system shall likely be limited as it shall need to have enough energy to maintain a stable quantity of energy within the system whilst not requiring too much of the blockchain running the LEM. This shall be further elaborated upon in Section 5.1.1.

Energy Consumption

The transition from consumer towards prosumer within the LES is not without its challenges. As presented in Figure 3.6 and 3.7 the highest load on the grid, especially in the case where solar generation is most prominent, is often not synchronised with the highest generation of energy. This furthermore does not even take the increasing penetration of EV into account that shall impact these discrepancies even more. Therefore, it requires the implementation of a much more complicated control and management system than the current system. Next to over-consumption and the discrepancies just mentioned, on the other side of the spectrum issues arise as well. One can think of over-generation which will require the grid to absorb the excess power during saturated supply within the LES' storage system. This is from an economic standpoint counter productive with regard to building incentive to invest in RESs as this could, in extreme cases, lead to negative electricity prices.(Parag and Sovacool, 2016)
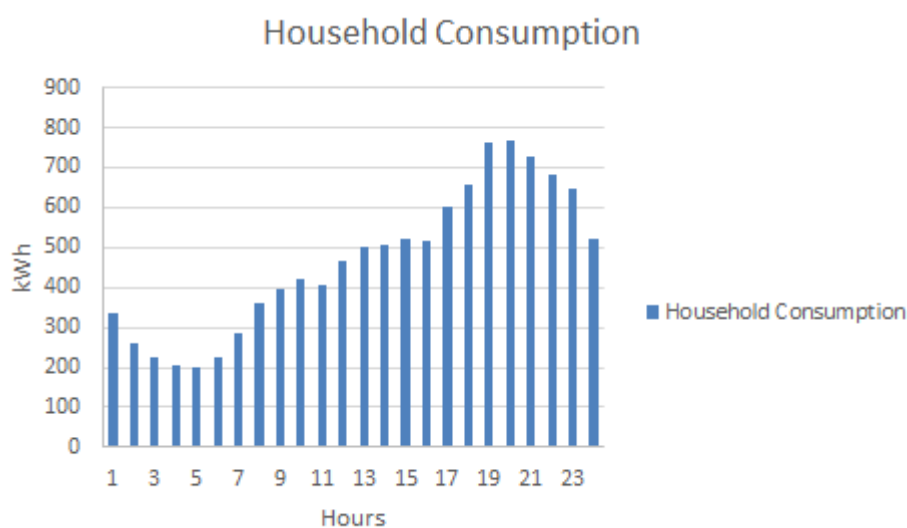
Figure 3.6: Household Consumption (NEDU, 2018)
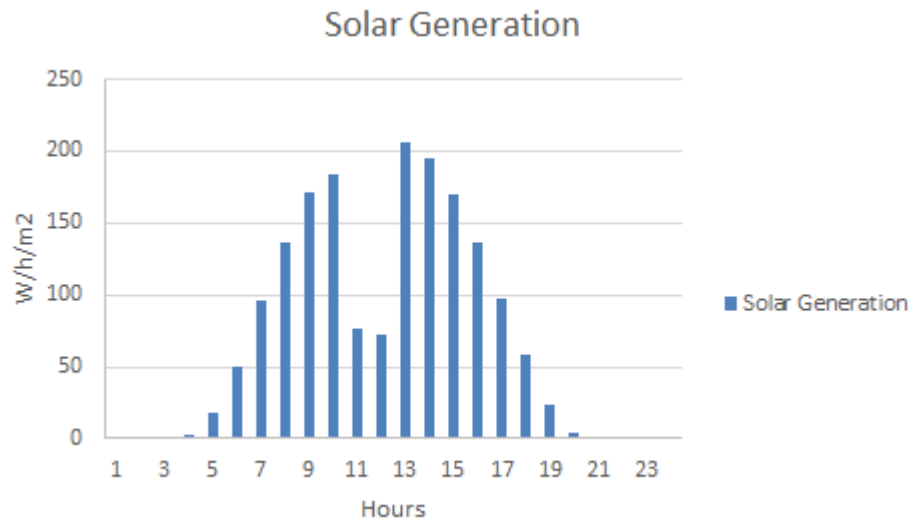
Figure 3.7: Solar Generation

Local Control System

Strasser et al. (2015) highlights the importance of a well-built control system in terms of power electronics and advanced ICT to manage the enhanced capabilities of the smart grid. Logically, the same holds true for the local energy system. With regards to the local energy system, this however entails that the IoT control architecture as well as the controlling and monitoring of the DERs shall have to be done via a local control system. This section therefore focusses on the local control system of the LES.

Besides the aforementioned functions, the LES intends to facilitate a local energy market. This thus requires the local control system to be able to facilitate a financial layer. This all to fulfil the consumers and prosumers demands and requirements, and to ensure the services of the smart grid. The function of the control system is thus threefold. First, it acts to control and monitor the IoT devices of the LES. Second, it acts to control and monitor the DERs of the LES. To elaborate, it intends to perform functionalities of a single distributed generator, storage or controllable load. This entails actions like voltage and frequency control, power control and protection. Third, to facilitate an information system that in turn facilitates the LEM. In Figure 3.8 the schematic representation of a local control system is provided.
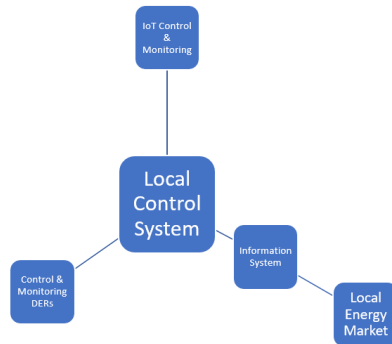
Figure 3.8: Schematic Overview of Local Control System

3.2.4 Conclusion

To conclude, this section attempted to provide the answer to the sub-question: 'What are the characteristics of local energy systems?'. First, the local energy market was defined to contrast the current manner in which the grid has been built up. Second, the adapted organised prosumer group model has been proposed establishing the place of the local energy system within the future energy domain or smart grid. This was followed by the dissection of the local energy system. We found that a local energy system generally consists of five layers namely: physical infrastructure and local sources, communication layer, control and protection layer, business models and regulatory framework. Out of the five layers, the latter four are considered to be within the scope of the research. To simplify, these were redefined as: distributed energy sources, energy consumption, (local) energy control system and business model. This section however solely focussed on the distributed energy sources, energy consumption and (local) energy control system. The distributed energy sources have provided the requirements for a local energy system to account for the intermittent characteristics of the renewable energy sources. This was furthermore supported by the discrepancies found in energy consumption and generation for normal households. The examination of the local control system has provided three tasks to be fulfilled which have been provided in a schematic overview. It was found that the control system shall have to deal with the IoT component of the local energy system, monitor and control the distributed energy sources and to facilitate an information system. The local energy market shall furthermore be a subsystem of the information system. The characteristics of the local energy system are lastly summarised in Table 3.1.

Table 3.1: Characteristics of a Local Energy System

Characteristics	*Functionalities*
Distributed Energy Resources	Generate Energy and Provide Storage
Energy Consumption	Consume Generated Energy
Energy Control System	Facilitate LEM and Facilitate Smart grid
Business Model	To understand how the business is intended to function

3.3   Local Energy Markets

This section shall focus on answering the second sub-question, 'What would be the key elements of local energy markets?'. First, the notion of local energy markets shall be defined. Next, the key elements of the local energy market are identified. The elements are then elaborated upon and architectures are proposed for each element. Last, the issues and challenges that are inherent to LEMs are researched and discussed.

3.3.1   Defining the Local Energy Market

A local energy market is a place in which prosumers, producers and consumers can trade locally produced renewable energy. This market, as the term suggests, is geographically constraint (in this case it would be within the LES) and has a distinct trading and pricing mechanism. This mechanism is subject to variables such as energy demand and generation. The LEM has the intention to provide the possibility of energy cost reduction and to boost the local economy by keeping the profits within the community. In doing so, an incentive is created to add additional RESs (Mengelkamp et al., 2018b). To facilitate a LEM there shall have to be met a number of requirements. Before we take a closer look into these there first shall have to be established what the objectives of a LEM are.

According to Mousa Marzband and Domínguez-García (2016) the main objective of local energy markets is to maximise the utilisation of RESs in a specific region. This can be viewed upon from a technical point of view as well as an economic point of view. The technical point of view entails features like power, voltage and frequency stability, power control and energy storage. The economic point of view refers to the business models involved and the different perspectives to the actors involved as to how this market should work for them. The provided definition however does not include the objective of the participants of the local energy market. As this research takes the need for self-sufficient and empowered prosumers into account from a business perspective the addition of this is necessary. The objective is therefore exactly that which just has been mentioned. For the participants to be self-sufficient and in control of their energy. In Chapter 6 the business aspect of the local energy market shall be further elaborated upon. In the following, the technical elements shall be presented.

3.3.2   The Key Elements of Local Energy Markets

Much like an LES, the LEM consists of a number of layers. Based on the findings of Teotia and Bhakar (2016), de Vries (2017b), Mengelkamp et al. (2018a) and Block et al. (2008) we derive the following elements:

- Market Design
- Information System
- Market Mechanism

The role of market design is to directly address issues concerning the organisational structure, regulation and the allocation of responsibilities in the electricity industry (de Vries, 2017b). However, regulations and organisational structure are considered to be outside of the scope of this research. Hence, the Market Design element can be categorised in two sub-categories: Ownership and Market Structure. Ownership refers to the objective of the involved actors. The smart grid is to facilitate the user with a bi-directional energy and information flow. Considering the objective of the LES and LEM there can be presented an aggregator role. There are a number of manners in which the aggregator role can be fulfilled, all providing different services to the customer as researched in Framework (2015). Second, the market structure refers to the place of the market within the traditional energy market. In Section 3.3.2 more on this shall be provided.

The information system shall function as the virtual layer to the LES. This thus entails that the information system is to handle the informational flow generated by the local energy market. To elaborate, the consumption and generation data that is generated by the households is transferred to the market which then processes this information. This leads to buy and ask orders following the policies that are predefined. These are transferred to the market mechanism resulting in payments upon which the physical layer is to transfer the energy to and from the actors. In Section 3.3.2 the proposed information system design is presented.

Lastly, the market mechanism refers to how the market functions, the pricing mechanism, payment rules, policies, etc. There are various manners in which this can be designed, Section 3.3.2 provides an initial proposal.

Design of a Local Energy Market

This section shall focus on providing a schematic overview of the design of a local energy market. The role of the aggregator is variable to three actors namely: the supplier, the DSO and the prosumers. In Figure 3.9 a local market design is proposed. Here it is clear that the role of the market system operator (or the aggregator) can be taken upon by the three aforementioned actors. Firstly, the incentive for the Supplier to take upon the aggregator role mainly comes from the reduced complexity with regards to the supply provisions. Secondly, the DSO's position is at risk with the coming transitions incentivising it to explore new business opportunities. The possible death-spiral referred to by Laws et al. (2017) can possibly be avoided if the DSO were to take upon the role of the aggregator. It furthermore has a beneficial position in the energy value chain, this is due to the intermediary role it fulfils within the energy system, which is to match the supply and demand from the grid and distribute it accordingly. Lastly, the Prosumers incentive is evident, however it is imperative that the prosumers have sufficient flexibility in order to effectively adopt the aggregator role. This would however be a role that is not profitable for residential prosumers as the burden is considered too high and the volume too low (Framework, 2015). This option thus is reserved for commercial and/or industrial prosumers only. These terms can be defined as: 'An industry that produces and makes use of renewable energy sources such as solar, wind, bio-energy, etc. to supply a portion or all of its on-site energy needs. In many cases, this includes selling excess energy or electricity to the national/local grid or to the surrounding community' (UNIDO, 2015). From this point onwards this shall be the prosumer referred to when the role of the prosumer is discussed in the context of the aggregator unless explicitly addressed. The role of the aggregator in all scenarios is further discussed and examined in Chapter 6.
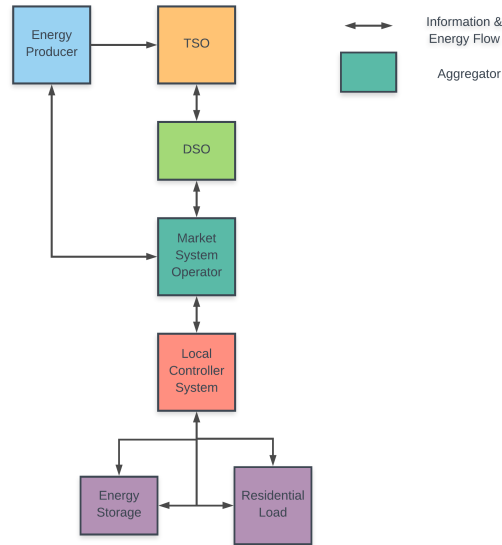
Figure 3.9: Proposed Local Market Design adapted from (Teotia and Bhakar, 2016)

Information System

As presented in Section 3.2.3 the information system is a subsystem of the local control system. In order to perform the functions, it shall first need to gather the relevant data like the generation and consumption data. This shall largely be done via the use of smart meters that are to be placed in every household. Importantly, this shall have to be done in a secure manner ensuring the privacy of the households. Additionally, the system is in charge of the energy storage system and enabling the flow of energy towards households and storage unit. In Figure 3.10 the information system is presented.
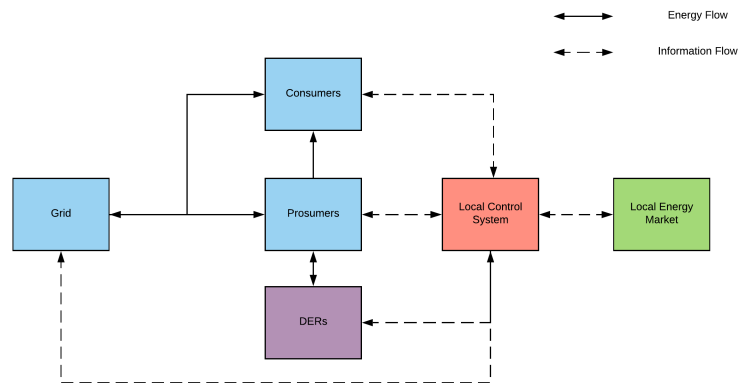
Figure 3.10: Proposed Information System Design

Market Mechanism

The function of the market mechanism is to provide the households with a real-time market based upon an auction mechanism. This requires a sophisticated pricing mechanism and demand/bidding strategies. There are several manners in which this is implementable, however, the manner in which this specifically is designed is hard to establish and highly dependable upon the actors. In Chapter 5 there shall be provided recommendations regarding the market mechanism and pricing mechanism as a result of the proposed blockchain configuration.
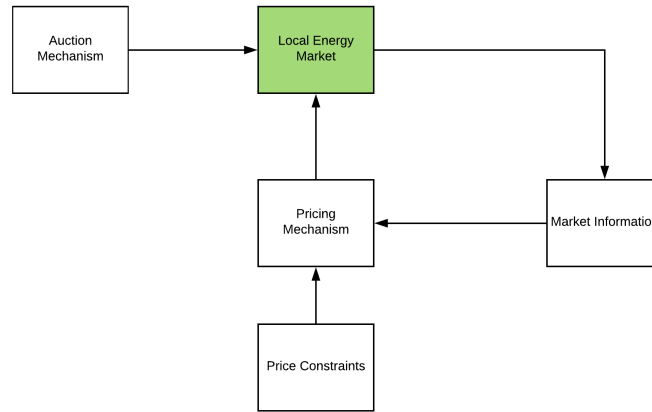
Figure 3.11: Proposed Market Mechanism

3.3.3 Challenges & Barriers

As a local energy market deals with innovative technology, regulations, economy and the environment there are some challenges and barriers to be overcome. This section shall discuss there following the aforementioned categories.

Firstly, the technological challenges and barriers are mainly constraint to the design and operations of the local energy markets. For both, there are many variables to consider like: high battery costs affecting storage, infrastructure and grid codes. These all require skilled workers and need to be well-engineered. Secondly, currently the regulations and policies regarding, for instance, privacy and reporting are continuously increasing. This thus requires time and resources to be spent in order to fulfil these requirements. Furthermore, in order to facilitate a local energy market, the entire process shall need to be planned from start to finish following a strategic plan. This requires the participation of the actors, setting objectives and research in order to form proper strategies. Thirdly, the economic challenges and barriers, to facilitate a local energy market shall require a significant amount of investment of time and resources. As the cost and payback period is high it is important to establish the gains as well as the costs. Lastly, however the fact that the intention of the local energy market largely revolves around being environmentally friendly it does require spatial distribution (e.g. low energy density renewable energy sources like solar panels require more space), generate noise (e.g. due to wind turbines) and involves many toxic properties (e.g. batteries).(Dutsch and Steinecke, 2017)(Pereira et al., 2018)

3.3.4   Conclusion

This section shall conclude the findings, answering the sub-question: 'What would be the key elements of local energy markets?'. By analysis of the literature, the three key elements of local energy markets were found to be: Market Design, the Information System and the Market Mechanism. The elements are furthermore summarised and provided in Table 3.2. Like the local energy system, these elements require the examination of two domains. One focussing on the business-science of local energy markets and one the technical approach.

Table 3.2: Key Elements of a Local Energy Market

Elements	Function
Market Design	To establish the objective, participants and form of traded energy within the LEM
Information System	To provide market platform, connect participants and monitor market operations
Market Mechanism	To facilitate trade and pricing mechanism

First, the design of the local energy market was proposed. Upon this architectural basis, the business models shall be built in Chapter 6. Second, the information system has been designed to visualise the information and energy flows. This design was appended by the proposed market mechanism. In the following chapter, the blockchain shall be researched to explore what functionalities can be fulfilled.

4 | Blockchain in the Energy Industry

This chapter consists of an elaboration of the technology that is the blockchain after which an exploration of the concepts, possibilities and implementations of the blockchain in the energy domain shall be provided. This in order to answer the third research sub-question: 'What is the value proposition of the blockchain with regard to the energy industry?'.

4.1 What is the Blockchain?

The origin of the blockchain dates back to 2008 when Nakamoto (2008a) introduced the world to Bitcoin. But what is the blockchain? Swan (2015) defined it as follows: 'The blockchain is the decentralized transparent ledger with the transactions records – the database that is shared by all network nodes, updated by miners, monitored by everyone, and owned and controlled by no one. It is like a giant interactive spreadsheet that everyone has access to and updates and confirms that the digital transactions transferring funds are unique.'. The technology behind the Bitcoin so to say. On this ledger, all transactions made by the users on the blockchain are recorded and distributed among its nodes. Each node is a representation of a computer connected to the network that uses a client to validate and relay the transactions on the blockchain (Swan, 2015). Lastly, the blockchain periodically synchronises such that all users are in possession of the latest ledger.

Via the use of cryptography the information is coded on the ledger to ensure safety. Every block on the chain has, due to the cryptography, a unique hash. New blocks are created through mining, mining effectively means the finding of a hash that suits the pre-set requirements. This is done by finding a suitable nonce for the data the block holds. The use of cryptography shall be further discussed in Section 4.2.

There are three blockchain categories. Blockchain 1.0, 2.0 and 3.0 which respectively represent the technology for the decentralisation of money, the decentralisation of markets and decentralisation of autonomous organisations (Swan, 2015). Blockchain 2.0, or the Ethereum blockchain, introduces smart contracts. These allow for the transaction process to be automatically executed. In short, a smart contract is a code that programs a contractual agreement between parties. The use of smart contracts allows the performance of credible transactions without the interference of third parties setting itself apart from regular transactions. These smart contracts facilitate, verify, or enforce the negotiation or performance of a contract (Tar, 2017). This concept is particularly useful in the case of the energy industry. In Section 5.2 the application of smart contracts in the energy industry shall be further elaborated upon.

In short, the blockchain holds the following concepts:

Key Architecture Concepts:

- Distributed

- Trustless

- Secure

- Immutable

- Dis-Intermediating

From these properties, Trustless, Immutable and Dis-intermediating are yet to be explained. Trustless entails that the blockchain does not need the individual nodes to trust one another due to the inherent properties of the blockchain. This is due to the fact that each node can validate the other parts of the blockchain. When looking at traditional currency exchanges or transactions there normally is an intermediary party like a bank or a payment provider such as Paypal. The blockchain however provides, due to the trustlessness of the system, a dis-intermediating aspect of the exchange of digital currencies. This means that there is no bank needed and thus there is no central party involved. Lastly, due to the decentralised and public nature of the technology, the data on the blockchain is considered to be immutable making the blockchain an incredibly secure way of performing transactions. More on this shall be provided in Section 4.2.1.

4.1.1 Throughput, Latency & Finality

To measure the performance of a blockchain often the throughput, latency and finality are the measured criteria. These are respectively the number of transactions that can be validated per second, the delay over the network with regards to the transaction and essentially the guarantee that the transactions are not mutable any more.(Swan, 2015)

4.2 Cryptography

This section contains a brief elaboration of some of the key concepts regarding the cryptography used in the blockchain. In the following, the key cryptographic concepts are listed. By elaborating on these concepts the most important safety aspects with regard to the blockchain shall be covered.

Key Cryptography Concepts:

- SHA-256 hash functions

- Nonces

- Public-private key encryption protocols

SHA-256 is part of the SHA-2 (Secure Hash Algorithms 2) set of cryptographic hash functions developed by the National Security Agency (NSA) (Penard and van Werkhoven, 2008). These functions intend to provide unique hashes given the data it encrypts. With respect to the blockchain, SHA-256 is a 32-bit function designed to produce a hash unique to the data that a block in the blockchain contains. Nonces refer to an arbitrary number that can be used only once to alter the hash such that it suits certain arbitrary conditions of the blockchain. Due to the nonce, it becomes significantly more difficult to generate the desired hash, resulting in a significantly more secure blockchain. Lastly, the Public-private key encryption protocols refers to the public key that is used to encrypt the data and the private key that is owned by the owner of the data which allows for the decryption of the data. The use of these two keys has two functions namely, authentication and encryption. In the blockchain technology, this protocol sends the public key to the network enabling the network to authenticate the transaction and keeps the private key hidden and within the possession of the owner enabling it to decrypt the data. In Figure 4.1 a visual representation is provided of this process. By combining the hash with the generated keys a digital signature is created that protects the transactions validity.(Microsoft, 2005),(Christidis and Devetsikiotis, 2016)
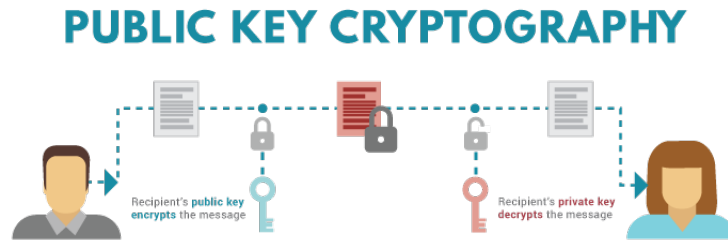
Figure 4.1: A Visual Representation of Cryptography in the Blockchain retrieved from Coinjolt (2017)

These three cryptographic concepts ensure for a very secure system which is virtually hack-proof. The aforementioned process of finding the right hash to match the arbitrary condition of the blockchain is called mining. This process generally works on the consensus mechanism called proof-of-work which shall be elaborated upon in the following section.

4.2.1 Proof-of-Work versus Proof-of-Stake

As the process of finding the right hash is done via the cryptographic puzzle it requires significant computational power. Due to this the system is very difficult to attack the system as an effective attack would imply that a node would have to solve >51% of the cryptographic problems of all the nodes in the blockchain. Which would require an immense amount of computational power. Due to this property, the blockchain can be considered to be a very safe system. In the context of the energy industry, this is especially true as the current system has proven to be hackable.(Conca, 2018)

The concept of finding the right has is called Proof-of-Work (PoW) (Nakamoto, 2008b) and as one can imagine requires a significant amount of electricity to maintain. This downside shall be later discussed when the application of the blockchain within the energy market is discussed in Section 5.1.1. PoW is used in blockchain 1.0 and 2.0.

Besides the PoW consensus mechanism, there is the consensus mechanism called Proof-of-Stake (PoS). This mechanism uses, unlike PoW, the stake of ownership as a manner to create and add new blocks to the blockchain. The creator of the new block is thus chosen via a combination of random selection and the amount of stake it holds. The mechanism relies on the rationale that users with a high stake will suffer the most if something were to happen to the blockchain. Thus, they will have the most interest in adding correct transactions to the blockchain (King and Nadal, 2012). Criticism on this consensus mechanism is mainly centred around the 'nothing-at-stake' problem. This revolves around the situation where there are multiple versions of the blockchain. In the PoS consensus mechanism, it requires nodes no resources and thus no opportunity cost to vote for either version. Due to this, there is no incentive to choose one of the versions unlike on the PoW blockchain. This results in a situation in which miners have nothing-at-stake to mine. This is nowadays however resolved by implementing safety mechanisms forcing nodes to choose a certain type of blockchain for instance.(Chepurnoy, 2016)

As PoS generally consumes less energy than proof of work (King and Nadal, 2012) this would suggest that PoS is a more viable option with regards to an implementation into the energy industry and especially to LESs. This shall be elaborated upon in Section 5.1.1 where the advantages and disadvantages of the blockchain within the energy industry shall be presented.

4.2.2 Byzantine Fault Tolerance

One of the most efficient PoS consensus mechanisms is the Byzantine Fault Tolerance (BFT). The Byzantine Fault Tolerance was first introduced in Castro et al. (1999) to address problems in embedded

computer systems. The name refers back to the Byzantine generals' problems, which is an agreement problem in which the generals need to agree on a common battle plan using but one communication channel. Which in the case of the blockchain technology can be described as the blockchain. The nodes of the network can be referred to as the generals and the battle plan is the valid blockchain. Generals can be traitorous or loyal and respectively would refer back to a dishonest and honest node in the network. Following the theory of the problem, the validation essentially entails a voting system in which a two-third majority is needed to achieve consensus. A visual representation is provided in Figure 4.2.
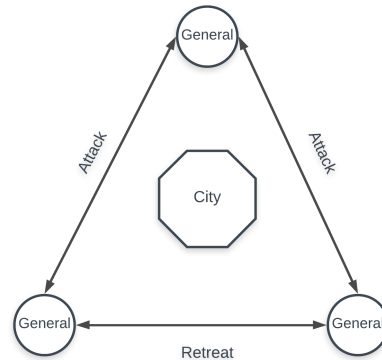
Figure 4.2: A Visual Representation of the Byzantine General Problem

Practical Byzantine Fault Tolerance

Castro et al. (1999) first proposed the practical Byzantine fault tolerance (pBFT) algorithm as a practical solution to reaching consensus when dealing with Byzantine failures. The pBFT is designed such that al the nodes in the blockchain are in a sequence ordered, with one node being the 'general'. The other nodes are referred to as backup nodes. The nodes all communicate with each other intending to acquire consensus. The algorithm is optimised such that it deliverers high-performance with but a slight increase in latency.(Curran, 2018)

4.3 Smart Contracts

The concept of smart contracts dates back from 1994 and was introduced by Szabo (1994). The idea of a smart contract is to embed the contractual clauses into code. This would minimise the need for (trusted) intermediaries between the parties involved. In the context of blockchain, smart contract are scripts that are stored onto the blockchain. This thus means that they have a unique hash, like the blocks. To execute the contract one would make a transaction to it, this triggers the script independently. Transactions between parties thus entail the contract to have three functions. First, it needs to allow a party to deposit a unit into the contract. Second, allow a party to withdraw units from the contract. Third, to facilitate a trade function between parties. For example, Party A deposits X units of currency A to the smart contract, Party B deposits Y units of currency B to the smart contract and in return the contracts trade the currencies and gives back to party A Y units of currency B and to party B X units of currency A. This logically could be traded in predefined ratios.

It must be noted that smart contracts also follow the cryptographic properties discussed earlier. This thus means that only parties with the corresponding keys are able to make use of the deposit and withdraw functions.

To conclude, the use of smart contracts to facilitate transactions within a LEM would be beneficial as it would allow for transactions to be completed automatically as the parties within the network are trusted nodes. The trading can be performed under predefined policies embedded into the smart contracts.

4.4 What Types of Blockchain are There?

Besides public blockchains like the one used for Bitcoin, there are also private blockchains. Furthermore, within these two sub-groups, there are again two different groups namely, permissioned and permissionless blockchains. In the following, these shall be discussed.

4.4.1 Public versus Private Blockchains

A public blockchain is defined as a blockchain in which there are no restrictions on reading blockchain data and submitting transactions for inclusion into the blockchain. This, however, may entail that this data can still be encrypted. A private blockchain is defined as a blockchain in which direct access to blockchain data and submitting transactions is limited to a predefined list of entities by Group (2015a), Group (2015b). Despite the fact that privatising the blockchain undermines two of the key characteristics and benefits of the blockchain namely trustlessness and decentralisation, it is not to say that these type of blockchains do not have a useful application. For example, private blockchains typically have a lower or no transaction costs as there as fewer nodes needed to verify in contrast to the thousands of computers needed in public blockchain. Furthermore, these nodes can be trusted to have high computational power as these can be hand-pickedButerin (2015).

4.4.2 Permissioned versus Permissionless Blockchains

The permissionless and permissioned blockchains are respectively defined as follows: 'A permissionless blockchain is a blockchain, in which there are no restrictions on identities of transaction processors (i.e., users that are eligible to create blocks of transactions)' and 'a permissioned blockchain is a blockchain, in which transaction processing is performed by a predefined list of subjects with known identities' (Group, 2015a). The difference in properties between the two is the following:

Table 4.1: Permissioned versus Permissionless adapted from (Wood, 2016)

Permissioned	Permissionless
Faster	Slower
Managed upkeep	Public ownership
Private membership	Open & Transparent
Trusted	Trustless

Now from this we thus find four type of blockchains: permissionless private, permissioned private, permissionless public and permissioned public. However, in practice three only really are made use of as permissionless private blockchains do not make much sense with regard to the fact that it puts restrictions on access and transactions but allows anyone to be involved in the consensus mechanism. Considering the other three, the permissioned private blockchain is to be the most viable option with regard to the blockchain facilitating a LEM. This is due to the fact that it restricts access to the data of the blockchain to those outside of the network, alleviating most of the privacy concern, and would not allow others to initiate or read transactions and validations of transactions. In Figure 4.3 a visual representation is depicted of such a blockchain. Furthermore, as the nodes can be trusted the operator can optimise the network in terms of finality, throughput, latency and energy consumption. Technically a system like this implies the system to not be fully decentralised, this thus goes against the inherent property of the blockchain.
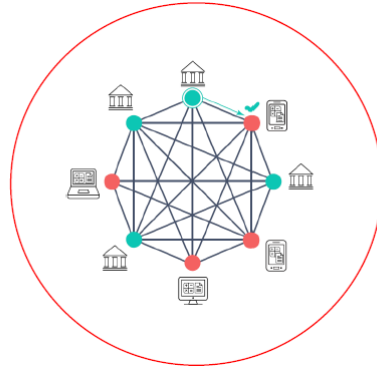
Figure 4.3: Visual Representation of a Private Permissioned Blockchain adapted from Froystad and Holm (2016)

4.5 Blockchain Projects in the Energy Industry

As mentioned in Section 3.1.2 the blockchain has the potential to provide the needed services for such a market. Currently there are some microgrid projects testing the usage of blockchain in their community. In the following some notable ones shall be discussed in order to provide an overview of the state at which the industry is with regard to implementing LEMs.

The following projects shall be discussed: Powerledger and the Brooklyn microgrid (BMG). These have been selected due to the fact that they are creating significant (media) interest, are well funded and make use of the blockchain technology. Additionally, the project in Feldheim, Germany has been selected to provide some more insight into how a grid-defected microgrid can be implemented, effectively working around the inherent challenges. However the fact that these projects are all making use of some form of blockchain technology it must be stated that these do work within the current way the energy industry system works.

PowerLedger
Powerledger is a company that makes use of a dual token ecosystem operating on two separate blockchains. The goal of the company is to enable consumers and businesses to sell their surplus solar power to their neighbours without an intermediary party. Powerledger intends to do so via the use of the two tokens (POWR and Sparkz). POWR allows application hosts and participants to access and use the platform of Powerledger. Sparkz is used by application hosts to onboard its customers. For example, a utility company using the Platform will be an Application Host, as is an EV-charging services business (Powerledger, 2018).

The Brooklyn Microgrid
The BMG is a project run by LO3 Energy. It consists of a microgrid located in Brooklyn and was started due to the outdated electrical grid in the Brooklyn area and severe weather events resulting in a unreliable energy supply. This combined with the increasing amount of energy consumption the BMG aims to provide solutions to the challenges of the Brooklyn electrical grid. The project makes use of a decentralised LEM and has its own physical microgrid acting as a backup to the existing grid(Mengelkamp et al., 2018a)(LO3, 2018).

Feldheim

The energy community of Feldheim is a self-sufficient microgrid that is grid-defected. However, there is a connection to the grid to transfer their surplus of energy. The Feldheim village is a special case in that they only consume 1% of the total generated energy and thus transfer and sell 99% of their energy back into the grid.(Feldheim, 2018)

To conclude, as shown the three projects are still in the start-up phases or even experimental phase. Powerledger and the BMG furthermore still fully rely on the back-up of the traditional grid and do not implement an energy storage system.

4.6 What Blockchain to Choose?

With the gathered knowledge about the blockchain, we can now focus on what blockchain is most suited for the context of this research. In the following section, there shall be considered a number of blockchains to find the most suitable one.

Considering the three categories of blockchains, it is clear that the blockchain 2.0 is most suited for a local energy market. This is due to the fact that it facilitates smart contracts which will allow for a market mechanism that is safe and efficient. Furthermore, as mentioned, considering the fact that there is no need for a public blockchain, a private blockchain is best suited. Considering the fact that the roles of the parties are well-established we can assume that the nodes are of good intentions. This thus allows for a safe permissioned blockchain which is desirable due to the more efficient nature in terms of energy consumption and potentially performance. Next, as the 'classic' Blockchain 2.0 or Ethereum makes use of PoW consensus mechanism, which is too slow for the high transaction rate and necessary scaling of the blockchain, there shall be considered a number of blockchains that make use of other consensus mechanisms. In Table 4.2 an overview is provided of the selected feasible blockchains.

Table 4.2: Overview of Permissioned Blockchains

Name	Consensus Mechanism	Tx/s	Smart Contract
Hyperledger Fabric[1]	Custom check	High	No
Tendermint[2]	pBFT	Medium	Yes
Chain[3]	Federated Byzantine Agreement	High	Yes
MultiChain[4]	pBFT	High	No
Ethermint[5]	PoS	High	Yes

Based on the properties, Chain and Ethermint are the two blockchains that seem most promising. Both make use of smart contracts whilst maintaining high Tx/s. Examining these further we find that the consensus mechanism is the most stand-out property that separates the two blockchains. Considering the federated Byzantine Agreement (FBA) consensus protocol in the context of a local energy market, we find that the network is likely too small to provide a trustworthy blockchain. This is due to the fact that the the protocol works in small overlapping groups which together form enough of a group to reach consensus. Regarding Ethermint we find it makes use of a PoS protocol that is based upon a pBFT consensus mechanism. This is generally considered to be more efficient than the FBA and therefore in conjunction with previous findings Ethermint is proposed as the blockchain that is best to facilitate local energy markets.

4.7   Conclusion

This chapter has attempted to provide the answer to the third research sub-question, 'What is the value proposition of the blockchain with regard to the energy industry?'. Summarising this chapter we find that the blockchain can theoretically function as the basis of the information system as well as the financial layer of a market mechanism providing the necessary security and privacy due to the cryptographic properties which address the need for smart contracts. Due to this requirement blockchain 2.0 has been considered as the blockchain that is most suited to facilitate decentralised local energy markets. However, the consensus mechanism that is most used for this blockchain is the Proof-of-Work consensus protocol, an inefficient and energy consuming mechanism that is considered to be unsuitable for this application. Therefore, in conjunction with the intended use of a private permissioned blockchain, there have been examined a number of blockchains that make use of different consensus mechanisms more efficient than a Proof-of-Work consensus mechanism. The most applicable blockchain was found to be Ethermint due to its pBFT-based Proof-of-Stake consensus mechanism. To conclude, blockchain brings local energy markets with a strong value proposition by facilitating all needed components of the local information system. In Table 4.3 the results are summarised.

Table 4.3: Private Permissioned Blockchain Properties

Name	Blockchain	Consensus Mechanism	Performance	Energy Usage	Smart Contract	Tx/s
Ethermint	2.0	PoS (pBFT-based)	Efficient	Low	Yes	High

In the following chapter, the synthesis between the LES, LEM and blockchain domains shall be provided in order to find the most relevant uncertainties to decentralised local energy markets.

5 | Synthesis

From Chapters 3 and 4 the characteristics of the LES, key elements of LEMs and the blockchain have been identified and researched. This chapter focusses on the synthesis of these components in order to answer the fourth research sub-question: 'What are the uncertainties of using a blockchain to facilitate a local energy market?'.

5.1 Implementing a Decentralised Local Energy Market

When looking at the use of the blockchain in the energy industry and especially with regard to the smart grid it is important to note that the use of blockchain in the energy industry mostly cannot go without the use of the Internet of Things. Therefore, in addition to the physical architectural changes of the LES, there shall have to be made alterations to the prosumers hardware architecture at their home. To enable the use of a blockchain each household shall have to make use of a smart meter combined with a software module that enables the local energy market capabilities. In Figure 5.1 a conceptual architecture is depicted. To enable the use of a blockchain, each household shall have to make use of such a smart meter combined with a software module that enables the local energy market capabilities. The combination of the two technologies, blockchain and the IoT, allows besides the peer-to-peer energy transactions for the potential of an increase in efficiency in the billing and clearing process for the consumers (Felix Hasse, 2016). The blockchain can thus be understood as an enabler for energy communities (Ioannis and Raimondo, 2017).
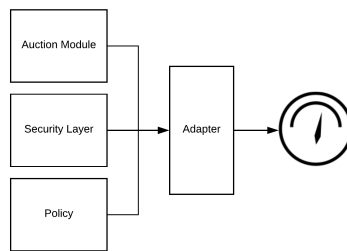
Figure 5.1: Conceptual Architecture of a Smartmeter

The module shall provide trading policies, facilitate energy trading and security. The latter two can be facilitated via the use of smart contracts. All of these components can be tailored to the prosumers needs. The smart contract with regard to energy trading shall be responsible for the auction, which consists of managing the buy and sell orders. The security part of the transactions is also handled by the smart contract which, as mentioned in Section 4.3, acts as a virtual contract. Moreover, it provides a safer environment as it can keep out vulnerable smart meters. With regard to the proposed set-up this is however not of significance to the LEM.(Mihaylov et al., 2014)

Following the work of Pop et al. (2018), Ioannis and Raimondo (2017) and the previous chapters we can deduct the functionalities of the blockchain in the energy industry provided in Table 5.1.

Table 5.1: Functionalities of the Blockchain in the Energy Industry

Challenge of the Grid	Blockchain Approach
Single Point of Failure	Decentralised System
Privacy	Energy Profile Anonymity
Transparency	Inherent Blockchain Characteristic
Energy Agreement Verification	Smart Contracts
Demand Response Programs	Smart Contracts, Automatic Signalling
Market Mechanism	Peer-to-Peer/Controller Functionality

Reflecting back on the findings of Chapters 3.3 and 4 it is important to understand what elements the blockchain can theoretically facilitate. In Table 5.2 the elements of the LEM are appended by the functionalities of the blockchain.

Table 5.2: Local Energy Market Elements versus the Blockchain Functionalities

Elements	Requirements	Blockchain
Design	To establish the objective, participants and form of traded energy within the LEM	✗
Information System	To provide a market platform, connect participants and monitor market operations	✓
Market Mechanism	Facilitate trade and pricing mechanism	✓

The table confirms the need for both a technical as a socio-economic integration approach needed to implement the decentralised local energy market, which was previously described by Koirala (2017). The table shows the design element of the LEM is not within the functionalities of the blockchain. This business science related element is therefore to be further examined in Chapter 6. However, the information system and market mechanism are within the functionalities of the blockchain. The blockchain can be used to facilitate the transactional layer of the LEM minimising the transaction costs. However, the manner in which this layer is facilitated is possible in multiple technical architectures. These shall be presented in Section 5.2.

5.1.1 What are the Advantages & Disadvantages of the Blockchain in LEMs

Now that it has been established that theoretically LEMs can be facilitated by a blockchain we are to examine whether it is actually desirable. This is to be done by looking at the advantages and disadvantages of the blockchain application used to facilitate ICT components of the LEM. In Table 5.3 the advantages and disadvantages identified by Mengelkamp et al. (2018b) are listed. When reviewing the disadvantages it can be concluded that especially the scalability, high energy consumption and the aforementioned high initial investment are disadvantages that could provide notable problems regarding the realisation of the LEM. It must however be stated though that the price of renewable energy photovoltaic batteries (PV batteries) is dropping and as researched in Hoppmann et al. (2014), Khalilpour and Vassallo (2015) and Andrei Ilas and Taylor (2017) the economic feasibility for a regular household is there. Furthermore, the investments costs are subject to drop even lower due to factors like the economy of scales.

With regards to the advantages, it is debatable whether transparency and irreversibility are truly advantages in the context of LEMs. It is highly likely that the participants of the LEM do not intend to make their financial transactions public, even if it is limited to the nodes of the LEM, and can in my opinion therefore be disregarded as an advantage. The irreversibility of transactions might furthermore pose to be a problem in conjunction with the fact that the blockchain is an immature technology. For example, if policies are wrongly enforced one could irreversibly sell their energy leaving them to draw energy from the grid defeating the purpose of the LEM. However, the irreversibility property does allow for a traditional market mechanism to take place. Due to the inconclusive nature with regard to the impact of these dis- and advantages these shall be further elaborated upon in Section 5.3 and following the trend analysis the most significant uncertainties are to be tested.

Table 5.3: Advantages & disadvantages of using blockchain technology as Information System in LEM (Mengelkamp et al., 2018b)

Advantages	Disadvantages
Distributed and secure data basis, bottom-up system	Complex technology and various unsolved challenges
Transparency, reliability and equality of agents	Scalability issues
No need for central intermediaries	High energy consumption
Cost-efficient micro transactions	Immature technology
Distributed and decentralised system	Social apprehension to new technology
Irreversibility of transactions	

5.2 Market & Pricing Mechanisms

The manner in which the energy is priced and traded among the community members can be designed in various manners. This section shall present some leading examples that should be taken into consideration with regard to the technical architecture of the local energy market.

As proposed by Ioannis and Raimondo (2017) the trading of energy within the LES can be performed in two ways. Either by directly buying energy from another prosumer within the LES (peer-to-peer trading) as depicted in Figure 5.2 or via a controlled system functioning as an energy storage system (peer-to-controller trading) as depicted in Figure 5.3. In both architectures, the households will get paid in a dedicated cryptocurrency (in the example Helioscoin).

As researched in Section 3.2.3 there is due to the intermittent nature of the energy sources a need for an energy storage system and thus peer-to-peer trading as a sole way of trading is considered infeasible. Considering these two architectures a hybrid of both trading mechanisms is proposed in Figure 5.4. This architecture allows for trading among the peers of the local energy system whilst also facilitating the trade towards the local control system that shall store the excess energy into the energy storage system. By making use of an Ethereum-based blockchain smart contracts can be incorporated.The design of the token-based trading is variable as is the design of the smart contracts that the community chooses to use.
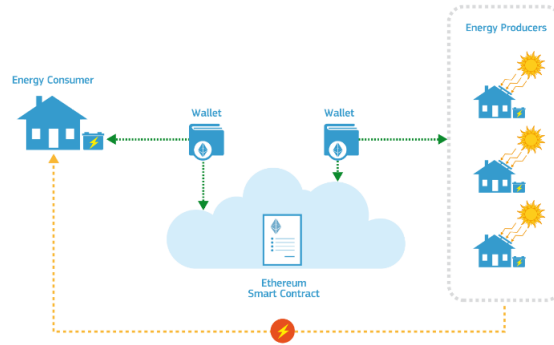
Figure 5.2: Peer-to-Peer Exchange of Energy retrieved from Ioannis and Raimondo (2017)
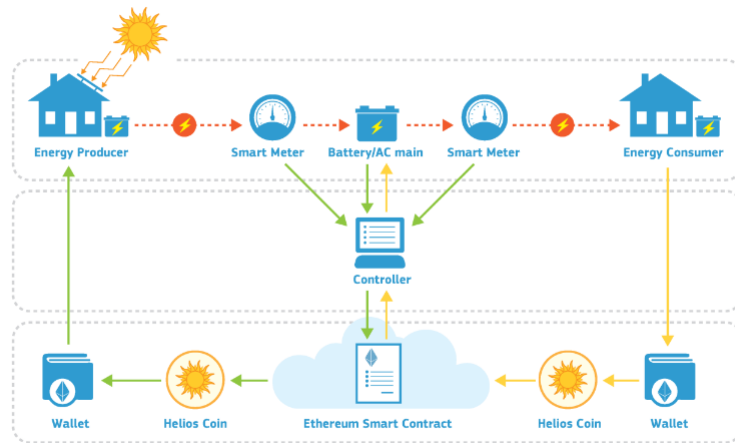
Figure 5.3: Peer-to-Controller Exchange of Energy retrieved from Ioannis and Raimondo (2017)
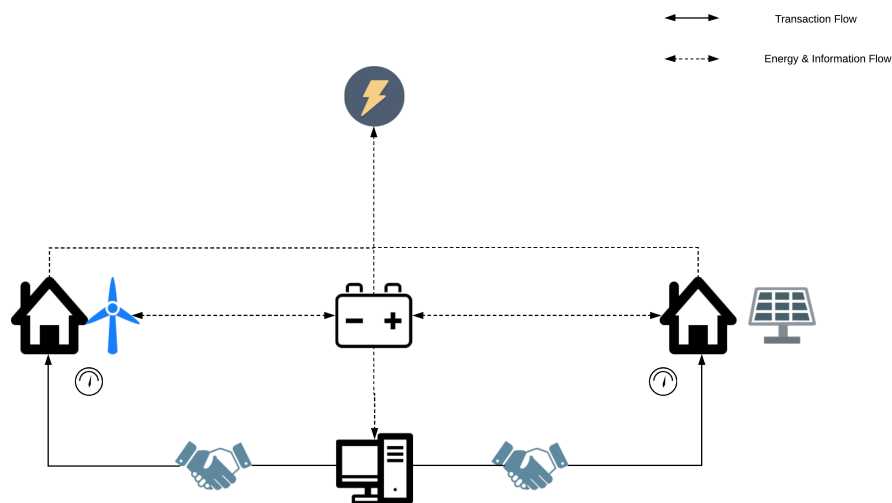
Figure 5.4: Decentralised Architecture

5.2.1 Pricing Mechanisms

Traditional energy tariffs consist largely of taxes and surcharges build up out of transmission, metering, distribution and connection costs (Commission, 2015). However, due to the fact that many of these charges do not apply to the LES the prosumers are able to turn their generated energy into profits. Generally, the pricing mechanism should be dependent upon scarcity and demand and as researched by Bayram et al. (2014) the auction mechanisms which are based on game theoretic approaches are advised for decentralised market solutions. To further examine the best game theoretic approach is however outside of the scope of this research.

Logically, the average price of energy is to be lower than the tariff of the traditional grid if the participants intend to profit from their energy. The blockchain technology provides various manners that can be utilised with regard to the bidding and billing of peers in the community. In Abidin et al. (2018) and Mengelkamp et al. (2017) several privacy-friendly protocols are examined, Abidin et al. (2018) billing protocol allows the supplier to bill the consumer without getting to know the details of the energy consumption. This would suffice for the technological architecture depicted in Figure 5.4 and thus could serve as an example for the decentralised LEM pricing mechanism.

5.3 Assessing the Disadvantages

Considering the findings of Mengelkamp et al. (2018b) this section shall consider some of the disadvantages of the blockchain.

Firstly, we consider the scalability trilemma as well as the factors influencing the scalability of the blockchain. The scalability trilemma refers to the scalability, security and decentralisation of a blockchain and was first introduced by the co-founder of Ethereum: Vitalik Buterin (Buterin et al., 2014). In the current development of the blockchain, there can only be guaranteed two of these properties. As the focus in the context of local energy markets is towards the scalability and security this thus requires us to not focus as much on the decentralisation of the market. This reflects in the decision to make use of a private permissioned blockchain. In theory, this therefore should greatly enhance the scalability of the local energy market. Keeping the scalability trilemma in mind, we shall now discuss the factors influencing the scalability itself. The performance of a blockchain is, as mentioned in Section 4.1.1, mostly measured by three criteria, in the following these shall be elaborated upon from a scalability perspective.

First, the number of nodes in the system (i.e. the number of households, energy storage, etc.). Although, scalability of the blockchain itself is not so much focussed on the amount of nodes but more on the throughput in terms of computing power. It is important to note that the system scales exponentially, namely following Equation 5.1. Considering the proposed Ethermint blockchain, we find that it is able to process about twenty times the amount of transactions per second of an Ethereum blockchain. Ethereum can store 380 transactions per block which equates to about 12.5 transactions per second whereas an Ethermint blockchain is able to process about 200 transactions per second. In contrast to the transactions per second of platforms like Visa (24000 Tx/s (Visa, 2018)) this is significantly less however, this system is implemented worldwide and not in a geographically constraint environment like an LEM. Furthermore, the local energy market works with an auction mechanism which introduces timeslots during which bidding takes place.

$$a_{n+1} = \frac{n(n+1)}{2} \tag{5.1}$$

The auction mechanism mainly relates to the second and third criteria: throughput and finality. These will ensure a smooth market mechanism and ensure transactions during trading periods respectively. As the transactions do not need to be processed immediately, the transaction speed is considered within acceptable margins at this point. However, the ideal timeslots shall have to be further established. In Section 8.3 more on this shall be provided. Furthermore, as the market shall make use of a permissioned

private blockchain the latency shall not be a problem considering the increased efficiency compared to a public blockchain. Lastly, the finality is nearly immediate as researched by Ethermint (2018) and thus should pose no problem.

This leaves the high energy consumption to be discussed. The work of Mengelkamp et al. (2018b) has been based on the consumption of energy for the Bitcoin blockchain, which as mentioned works on a PoW consensus mechanism and is significantly less efficient as the proposed Ethermint blockchain which makes use of a highly efficient PoS consensus mechanism which has been brought to life exactly for the reason to counter the high energy consumption of the PoW consensus mechanism (Zheng et al., 2017). However, due to the inconclusive results, it is deemed necessary to further research the energy consumption in future work. More on this shall therefore be provided in Section 8.3.

5.4   The Blockchain-Enabled Prosumer Business Model

As a result of the synthesis we can now define the business model of the blockchain-enabled prosumer (those participating in an LES and LEM). This looks at the consumer turned prosumer within the transitioned energy system, to lay a basis and provide a contrast to the innovated BMCs that shall be presented in Section 6.2. Furthermore, this will assist the DSO and Supplier during the making of their business case (e.g. SWOT and Porter-analysis). As one can see the prosumer is greatly empowered but is subject to the variation in aggregator roles that can be fulfilled. This thus entails the customer relationship to be altered. As this is a significant aspect with regards to the BMs the customer relationship between the actors shall be further discussed in Section 6.2.3.
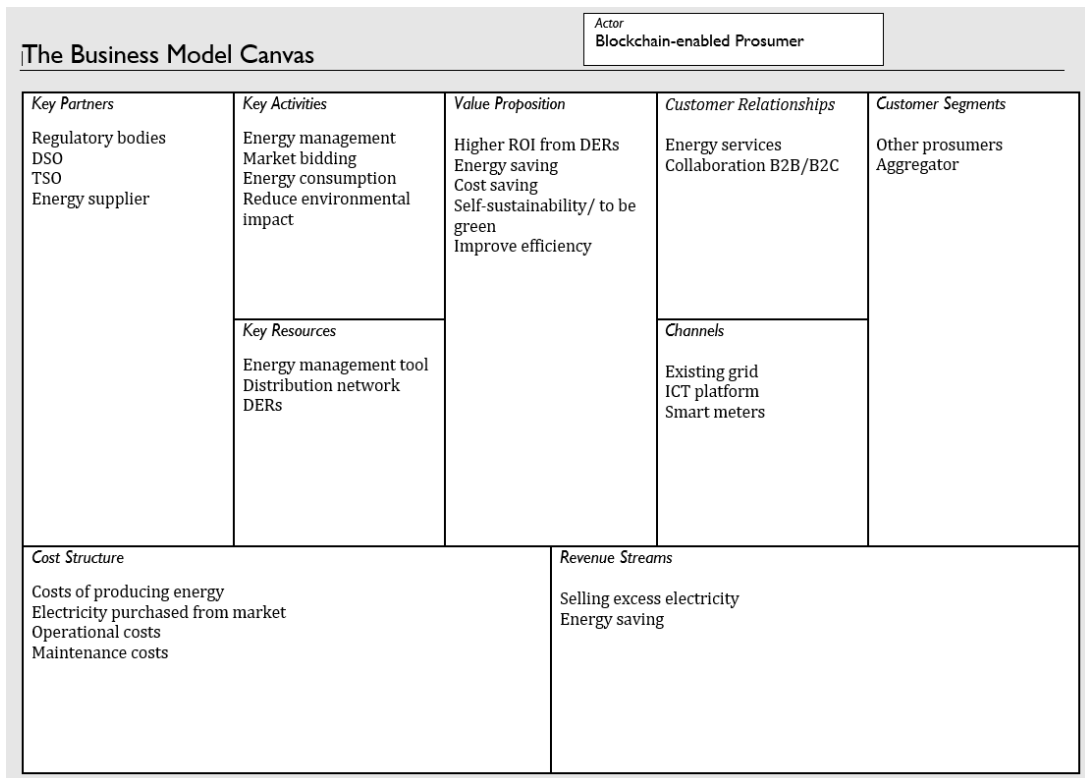
Figure 5.5: Business Model Canvas Blockchain-Enabled Prosumer-Oriented

5.5   Trend Analysis

This section shall provide a trend analysis on the transitioning energy landscape. This shall be done in order to be able to properly make a selection of the uncertainties. The analysis shall make use of the work performed by Kuiper (2015) and Koirala et al. (2016b). These have been chosen due to their relevance to this study, great number of assessed papers and the inefficiency of redoing the analysis.

Firstly, a team of Enexis Bv (a leading DSO in the Netherlands) has gathered a total of 909 trends during an research based on a number of 34 documents taken from reports by companies like PWC, Deloitte, the Harvard Business Review, TenneT, and KPN. Furthermore, there have been conducted interviews on 20 experts of the field combined with two workshops. In order to be able to manage the 909 trends the team then used a STEEP (Social, Technological, Environmental, Economic, Political) categorisation and ranked them for relevance. A second workshop was held which reduced the number of trends to 29. In Table 5.4 the 29 trends are listed.

Secondly, the work of Koirala et al. (2016b) is more centred around the energy communities and thus is considered a good addition to the presented trends. The research has taken 1285 publications into consideration which were clustered into 12 themes. Which resulted in 5 identified trends listed in Table 5.5.

Table 5.4: Trends clusters by Kuiper (2015)

Trend cluster name Overall	Category
1. Acceleration of technological breakthroughs	
New technological developments emerge for existing technologies (efficiency rises?)	Technical
2. Increase of affordable and available energy storage possibilities	
Storage and conversion to energy carriers which can be relatively easily stored.	Technical
3. Increase in large-scale (central) sustainable electrical production	
Shifts between energy carriers (electricity, gas, heat) in the central energy production.	Technical
4. Increase in decentralized energy production	
Production shifts from centralized production to decentralized production.	Social
5. Increasing awareness / attention for sustainability	
There's an increased awareness and attention to sustainability, both intrinsic at consumer as stimulated by the government (in the form of subsidies, CO2 taxes)	Social
6. Increasing scarcity of resources	
Resources like fossil fuels and raw metals become scarce. Also there's a shortage of room for the production of biofuels. The result is a price increase of resources.	Economical
7. Increasing complexity of energy distribution	
Due to changes in supply and demand the requirements to the physical energy network change. The networks become more complex, among others due to the increase in the usage of IT in the networks.	Technical
8. Increase in the amount of new energy services and service providers	
There is an increase in service providers on the field of energy and a corresponding increase in the amount of services which can be provided. Developments at service providers are speeding up (energy savings, demand-side management, flexibility)	Economical
9. Decreasing energy usage of the end user / client	
Energy usage in the residential sector decreases, on the one hand due to better insulation and local energy generation, on the other hand due to increasing energy awareness. There are more and more energy users in and around the house which could make the energy usage 'behind the meter' rise.	Social
10. Increasing customer involvement with energy	
Energy becomes more important. Customers are consequently more demanding and expect more from DSOs in terms of information, service etc.	Social
11. Increasing urbanisation and shrink regions	
Urbanisation and shrink regions change demands in investments in these regions.	Economical
12. Economic model develops towards more bottom-up initiatives	
There are more and more local and small-scale initiatives, in which ownership and usage are handled differently.	Economical
13. Increasing instability of global financial systems	
Integration of global financial markets expands local problems to a larger area.	Economical
14. Increasing desire for meaningfulness	
The public debate shift from doing the things right, to doing the right things. This leads to different choices on the balance of work and the private environment.	Social

Trend cluster name Overall	Category
15. Increasing government steering / regulation on the energy market Energy is becoming an important topic in politics. As a result the government interferes more on security of supply. Regulation increases both nationally and from the EU.	Political
16. Increasing flexibility of the labour market Legal principles of fixed contracts and freelancers are more and more similar. More and more people have a flexible working relation.	Economical
17. Sustainable transport rises As the transport sector is required to become sustainable, a shift occurs towards transportation with no direct fossil fuel usage. Electric vehicles, hydrogen vehicles and transport based on green gas rises.	Technical
18. Increase in public involvement with energy related questions The public is more involved with projects concerning storage, gas, CO2 collectors etc. and also carries strong opinions on them.	Social
19. Increasing desire for self-sufficiency Increase in human (individual) independence of existing institutions. Self-sufficiency is a priority	Social
20. Increase in number (and tasks) of energy corporations Collective self-sufficiency rises tasks and complexity of corporations will increase, from production to distribution and delivery.	Economical
21. Emergence of new energy carriers / forms of energy Among others nuclear fusion, LNG, biogas, shale gas, ´heat´ as source, hydrogen.	Technical
22. Increasing need for flexibility to account for fluctuations in energy supply and demand Increasing need for controllable generation and controllable usage for a better fine-tuning of variable supply and demand. Examples are controllable generation and dynamic tariffs.	Technical
23. Increase in the importance and usage of data The amount of data and the connection between data from various sources are increasingly more important, providing options for new forms of services and monitoring.	Technical
24. Increasing contradictions in the society Increasing contradictions arise between 'have's' and 'have-not's'. For a growing group of people access to new digital applications is becoming a problem the energy bill threatens to become too expensive.	Social
25. Increase in geopolitical unrest This can lead to new collaborative efforts and / or more need for self-sufficiency.	Political
26. Increase in specialisation and collaboration in / over the value chain Through increasing complexity in the energy value chain and specialisation of firms there is an increasing need for interdependence.	Economical
27. Emergence of the (bio-based) circular economy Increasing scarcity of resources lead to the emergence of a circular and bio-based economy. Renewability and reusability of resources are key.	Economical
28. Increase in integration between electric, gas, and heat through local optimisation More often than not people look for the best solution on a local level by integrating energy carriers.	Technical
29. Increase in aging population The aging population leads to a labour shortage and requires firm attention to the field of customer communication.	Social

Table 5.5: Trends identified by Koirala et al. (2016b)

Trends	Description
1. Increasing electrification	The energy consumption shall rise significantly due to the de-carbonisation and increasing energy demand.
2. Rising distributed energy resources	In the smart grid system, users are expected to utilise distributed generation and storage technology in their homes.
3. Towards a carbon-neutral energy mix	Increased policies towards a low-carbon future and an increasing number of intermittent renewable energy sources.
4. Changing utility business models	Due to the changes within the industry the business models need to be innovated.
5. Increasing customer engagement	Increasing number of customers are expressing their goal to become self-sufficient and carbon-neutral in energy.

Cross-comparing the trends found by Kuiper (2015) and Koirala et al. (2016b) in Table 5.6 allows a clustering of the trends narrowing down the number from 34 down to 23. This thus entails the trends found by Koirala et al. (2016b) to encapsulate the trends that coincide following the comparison. To further narrow down this number there have been set-up three criteria upon which the trends are re-clustered. This is to determine the relevance of the trends to this research and determine the most important ones.

Table 5.6: Cross-Comparison

Trends by Koirala et al. (2016b)	Overlapping Trends by Kuiper (2015)
#1	#22
#2	#2 , #4
#3	#15
#4	#8, #12
#5	#10, #12, #14, #18, #19

The proposed three criteria are formulated as follows:

- Affecting the potential adoption rate of renewable energy sources.

- Affecting the potential adoption rate of the blockchain technology and/or the smart grid.

- Affecting the energy value chain (e.g. services, business models).

Applying these criteria to the remaining trends we find the trends depicted in Table 5.7 to be of most relevance to this research:

Table 5.7: Most Relevant Trends

Trends	Description
1. Increasing electrification	The energy consumption shall rise significantly due to the de-carbonisation and increasing energy demand.
2. Rising distributed energy resources	In the smart grid system, users are expected to utilise distributed generation and storage technology in their homes.
3. Towards a carbon-neutral energy mix	Increased policies towards a low-carbon future and an increasing number of intermittent renewable energy sources.
4. Changing utility business models	Due to the changes within the industry the business models need to be innovated.
5. Increasing customer engagement	Increasing number of customers are expressing their goal to become self-sufficient and carbon-neutral in energy.
6. Increase in the importance and usage of data	The use and importance of data is increasing. Interconnectivity of data, people and systems results in more information provision and the emergence of new services and monitoring.

5.6 Selecting the Uncertainties

With the gathered answers on the first two sub-questions of the research combined with the trend analysis the uncertainties can now be derived. This chapter has synthesised the blockchain domain with the established LES and LEM domain assessing what functions can be fulfilled by the blockchain technology.

As recommended by Bouwman et al. (2018) the number of uncertainties is to be limited in order to keep the stress test manageable. Therefore, there has been chosen to make use of three categories: Technical, Economic and Social. These logically follow from the trends gathered in the previous section and largely coincide with the findings of Hyytinen and Toivonen (2015). Within these categories, there shall be selected two uncertainties which shall be elaborated in the following. In Table 5.9 the categorisation and descriptions are provided.

Table 5.8: Categorisation of Uncertainties

Type	Description
Technical	Uncertainties related to the technical capabilities
Economic	Uncertainties related to the potential economic impact of LEMs
Social	Uncertainties related to the social impact on the participants

The uncertainties have been selected based upon the literature that has been discussed in the previous chapters combined with the trend analysis. The trend analysis has been primarily used in order to select the most prominent uncertainties and to allow the stress test to be tested upon the most relevant uncertainties whilst ensuring the test to be manageable.

5.6.1   Technical Uncertainties

Based upon the literature review of the LES, LEM and the blockchain there has been established a technical basis upon which the decentralised LEM is to be built. However, there are some clear uncertainties with regard to the technical characteristics of the blockchain technology and the local energy system that shall have to be implemented to facilitate the energy market. the first uncertainty shall therefore be the potential biggest challenge of the blockchain, scalability. The second uncertainty, complexity, has been chosen as a result of the fact that both the concept of local energy markets as the blockchain technology are in its infancy. The technology is slowly finding its way towards suitable implementations and (decentralised) local energy markets is one of these. This is exemplified in the fact that currently they are only found in experiments and pilots. In the following, the two technical uncertainties are discussed.

Uncertainty 1 - Scalability

The scalability assesses the extent to which an LES can be scaled whilst being feasible. This takes up-scaling as well as down-scaling into consideration. The scaling of the market takes the ability of the blockchain into consideration with regards to throughput, finality and latency and as a result of a higher scale implementation the increase in these factors.

Uncertainty 2 - Complexity

The complexity refers to not only the use of the technology (e.g. management, maintenance, etc.) but also the unsolved challenges due to inherent characteristics of the blockchain or for instance its relative immaturity. This is especially relevant within the energy industry as there are but a few pilots running at the moment.

5.6.2   Economic Uncertainties

From the synthesis, we can establish that the implementation of a decentralised local energy system shall not be without challenges. The blockchain is notorious for its high energy consumption and thus shall influence the price of energy within the market. This is therefore the first chosen economic uncertainty. The second economic uncertainty shall be the cost of implementation. As shown, the LES, LEM and blockchain all require significant investments in order to operate according to the demands of the participants.

Uncertainty 3 - Energy Costs

The cost of energy refers to the price participants need to pay per KWh. The intent of the system is to provide the participants with a lower energy tariff than their current grid tariff. However, with the implementation of the LES and LEM, there are some significant factors to be taken into account like the blockchain. Due to the dedicated components needed to facilitate the LES and LEM the average energy consumption per participant is much higher than for normal households. On the other hand though, with the current proposed architecture of the LEM the transaction costs are mitigated, energy is self-generated and there are no margin fees.

Uncertainty 4 - Cost of Implementation

The implementation cost speaks for itself. This is however a tricky uncertainty due to the fact that it is difficult to truly say what specific investments are towards a decentralised LEM as many of the technologies and investments are already being made due to the emergence of the smart grid (e.g. smart meters). Furthermore, as mentioned, it is debatable who exactly is to pay for these initiatives. Due to this, it is assumed that the costs of implementation are to be taken upon by the actor that is discussed in the respective business model.

5.6.3   Social Uncertainties

With growing concerns about privacy due to the emergence of big data, IoT and the smart grid the social uncertainties are of great significance. The General Data Protection Regulation (GDPR)(Voigt and Bussche, 2017) shall enforce the actors to guarantee that the data of the customers is protected with regards to the ownership, pseudonymisation, access, portability and the right to erasure. Therefore, the first uncertainty that shall be assessed is Privacy. The second uncertainty shall be based on the willingness to adopt the technology. In the following, the description shall be provided.

Uncertainty 5 - Privacy

Besides the regulations that the blockchain shall have to comply with, it is important for the local energy system to be at least as but preferably (much) more secure than the current system. Therefore, this uncertainty can be considered to be both social as technological. The blockchain that is to facilitate the system shall need to be able to withstand possible attacks to the system at a performance where the participants do not question it's ability.

Uncertainty 6 - Adoption

The willingness of the participants is of great influence with regard to the robustness of the business model. In the changing energy landscape it is furthermore the case that the participants are expected to be more involved which can also be deducted from the trend analysis. In Section 6.2.3 there shall be more on the changing relationship between producer and consumer. The adoption thus does not limit itself to just the adoption of new technology but also the willingness to be part of the energy industry in the role that shall have to be fulfilled as an aggregator or business partner.

5.6.4   Scenarios

In this section the uncertainties shall each be split into two scenarios one worst-case and one best-case resembling the most contrasting scenarios.

Firstly discussing the scalability, the two possible outcome scenarios are the situation in which the system is unable to timely handle the transactions and likely consuming a significant amount of energy in the process or a system able to handle the transactions efficiently both time-wise as energy-wise. These shall be named negative and positive in the template for simplicity. The two scenarios concerning complexity are on the negative end of the spectrum a system that is hard to manage and on the other end a manageable system. With regard to the energy costs scenarios, the two possible outcomes are relatively straight forward and shall be proposed as either below or above the current tariff. The cost of implementation uncertainty outcomes are similar and are either high or low. The security uncertainty shall mainly focus on the increasing regulations. This is due to the fact that if the system is to be in compliance with the regulations the system can be deemed secure and will ensure privacy. On the other side of the spectrum, this would entail an insecure system. The adoption uncertainty outcomes are on the one hand the participants are willing to adopt the system and on the other hand they are unwilling.

5.7   Heat Map Template

As a result of the findings of this chapter the heat map template can be made. In Figure 5.6 the template is depicted.

Actor	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments												
Value Propositions												
Channels												
Customer Relationships												
Revenue Streams												
Key Resources												
Key Activities												
Key Partners												
Cost structure												

Figure 5.6: Heat Map Template

5.8 Conclusion

This chapter synthesised the energy domain with the blockchain technology to provide the final step of the technical approach. This was done by first considering the implementation of the blockchain for the proposed local energy system and market. Resulting from this we found that the blockchain can facilitate two of the three key elements of the local energy market, namely: the information system and the market mechanism. Next, the properties were considered and the advantages and disadvantages of the blockchain as a facilitator of the local energy market were assessed. A market mechanism was proposed to fulfil the requirement of the local energy storage system along with a proposed pricing mechanism. Next, resulting from a trend analysis of the developments in the energy industry, the uncertainties were established. This has resulted in the ability to now answer the fourth research sub-question: 'What are the uncertainties of using a blockchain to facilitate a local energy market?'.

We considered 34 trends which were categorised and clustered into three uncertainty categories, namely: Technical, Economic and Social. These three categories are provided to cover the most relevant and important aspects of the decentralised local energy market. To further elaborate on these uncertainties there were identified two criteria per category and two scenarios per criteria. These resulted from the trends and technical requirements found from the synthesis of the domains. In Table 5.9 these are provided.

Table 5.9: Selection of Uncertainties

Uncertainty	Type
Scalability	Technical
Complexity	Technical
Energy Costs	Economic
Cost of Implementation	Economic
Privacy	Social
Adoption	Social

In the following chapter, the business models shall be provided that shall be stress tested against the uncertainties resulting from this chapter.

6 | A New Business Model

This chapter shall focus on answering the fourth sub-question, 'How may a blockchain facilitated local energy market be implemented in local energy systems?'. In order to answer this question first, the energy value chain shall be innovated. This shall be done such that it represents the situation relevant to the proposed context of local energy systems. Next, the aggregator roles shall be defined for the relevant actors. We then have the necessary elements to provide the innovated business model canvasses. To further examine the blockchain value proposition to the business models there shall be provided value proposition canvasses. Lastly, in Section 6.2.3 there shall be a discussion regarding the role of the customer relationship with regard to the business model innovation process.

6.1 A New Value Chain

This section shall first provide the value chain for the local energy system. Second, it shall define the role of the aggregator for all actors.

Referring back to the proposed local market design presented in Figure 3.9 as well as the proposed local energy system presented in Figure 3.5, we can deduct that due to the proposed changes and transition in generation source from conventional towards renewable energy, that there are now three of the four processes that are affected within the presented energy value chain in Figure 3.2. These would be: the generation, distribution and consumption process. As the consuming actors are now generating a significant portion of the LES consumed energy and the role of the aggregator is either to be taken upon by the supplier, DSO or prosumers, the value chain is to be altered. This provides us with the value chain presented in Figure 6.1.

As depicted, the role of the aggregator is now presented as an undefined role. This thus presents a new business opportunity which shall require an innovation to the business model. As a result, this shall help to fulfil the changing demands and roles within the energy system as a whole, but more drastically on the LES-level. In the situation where the DSO or the Supplier were to take upon the aggregator role, it must be noted that the prosumer shall have to develop a business model as well. This is due to the fact that they are increasingly becoming more important to the energy system and in the context of this research imperative to the local energy system.(Richter, 2012)
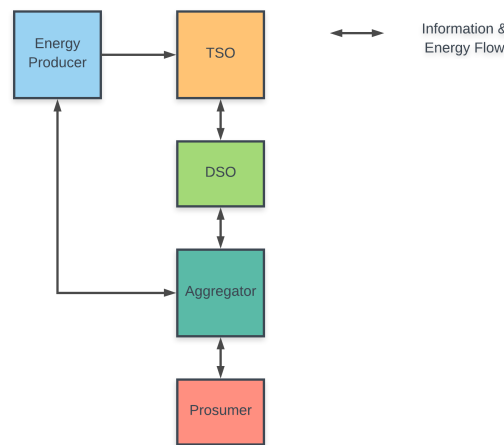
Figure 6.1: Local Energy System Value Chain

6.1.1   Defining the Role of the Aggregator

As the aggregator role can be taken upon by different actors within the innovated energy value chain, it is important to first define the role per actor. In the following three variations shall be defined and presented, namely: Supplier-Aggregator, DSO-Aggregator and Prosumer-Aggregator.

Supplier-Aggregator

Assuming the supplier to take upon the aggregator role allows the supplier to offer the prosumers a supply contract that also features flexibility options. This will reduce complexity as the supply and flexibility provisions can be aligned from the start (Framework, 2015). This allows the supplier to profit from the energy supply deficit and optimise their portfolio (Koirala, 2017). This role will bring the supplier closer to the consumer providing excellent scope for the integration of flexibility as part of the electricity service it offers to the customer.

DSO-Aggregator

Assuming the DSO to take upon the role of the aggregator for the LES there are six identified flexibility services it can provide, namely (Framework, 2015)(Force, 2015):

1. Congestion management
2. Grid capacity management
3. Controlled islanding
4. Redundancy (n-1) support
5. Voltage problems
6. Power quality support

The most relevant ones to the LES are Controlled islanding, Grid capacity management and Congestion management. These respectively refer to, avoiding the thermal overload of system components by reducing peak loads, aiming to use load flexibility primarily to optimise operational performance and asset dispatch by reducing peak loads, extending component lifetimes, distributing loads evenly and to prevent supply interruption in a given grid section when a fault occurs in a section of the grid feeding into it.(Framework, 2015)(Force, 2015)

Prosumer-Aggregator

By taking upon the aggregator role the prosumer can directly enter the flexibility market. As an aggregator the prosumer shall benefit from the following flexibility options (Framework, 2015)(Force, 2015):

1. Self-balancing

2. Time-of-Use optimisation

3. Controlled islanding

4. Control of the maximum load

These benefits are all relevant to the prosumer in the context of local energy systems. A mentioned downside however is the high burden that comes with being an aggregator, especially if the volumes are relatively low (Framework, 2015). The question is thus raised if the benefits outweigh the costs. To further investigate this, the business model shall be stress tested to identify the potential weaknesses in Section 7.2.2. Furthermore, in Section 8.3 the recommended additional research on this is discussed.

6.2 Disrupting the Business Model

Having defined, the local energy system value chain, the aggregator roles and innovated the energy value chain we can now start innovating the business model. There shall be provided innovated business models for each of the three aforementioned aggregator roles. As the business model provides little context of the environment in which the business is operating there shall also be made value proposition canvasses for each actor.

6.2.1 The Innovated Business Model Canvasses

With the reference business models presented in Figure 3.4 and 5.5 in place, we can now specify the innovated business models for the DSO, Supplier and the Prosumer.

First, in Figure 6.3 the BMC for the DSO in the aggregator role is presented. The most notable changes are within the customer relationship block which now not only consists of the energy services provided, but also the collaboration aspect with the participants of the LES. The relationship shall shift focus towards one that is based on trust and cooperation instead of loyalty. The revenue stream shall be increased due to gains from transaction fees and the exploitation of the green image it can establish. Next, the value proposition has changed. More precisely, the quality of the value proposition is changed here due to the value added by the RESs and there shall be fewer problems with grid control (e.g. power balancing, power flexibility, etc.).

The Business Model Canvas

| | | | | Actor
Aggregator-DSO |

Key Partners	Key Activities	Value Proposition	Customer Relationships	Customer Segments
Prosumers DSO TSO Electricity supplier BRP Customers/Prosumers	Energy management Market bidding Microgrid creation Demand response Energy consumption Reduce environmental impact	Transparency of sales Security Sale of electricity Lower electricity prices Improve efficiency Self-sustainability/be green Reduce grid losses Cost saving Higher gains from DERs	Energy services Collaboration (B2B/B2C)	Prosumers Consumers
	Key Resources Energy management tool Distribution network Electricity to cover the imbalance of the system ICT platform		**Channels** Existing grid ICT infrastructure Markets Media (TV, Internet, etc.) Energy bills Smart meters Company website	

Cost Structure	Revenue Streams
Costs of producing energy Electricity purchased from market Operational costs Maintenance costs Staff costs	Transaction fees Share of margins Cutting costs (e.g. grid servicing costs) Increased customer base due to green image

Figure 6.2: Business Model Canvas DSO in the Aggregator Role

Second, the Supplier BMC depicted in Figure 6.3 does not differ that much from the DSO's BMC this is due to the fact that the role of the aggregator is largely the same considering the (limited) level of detail the BMC displays. The main difference lies in the value proposition. This is to be expected as this BM component is directly influenced by the blockchain and introduction of the local energy market.

Figure 6.3: Business Model Canvas Supplier in the Aggregator Role

Third, the BMC for the industrial and commercial prosumers is provided in Figure 6.4. Comparing this BMC to the blockchain-enabled prosumers BMC it exemplifies the impact the system shall have on the prosumer. Besides a variety of value propositions and revenue streams it also adds a significant amount of key resources and activities that shall need to be managed. Comparing this to the previous two BMCs there is not much difference in these two components. Which confirms the likely unprofitable character of the aggregator role for local energy systems. Last, the customer segment is very rich in actors as well as the key partners. These shall have to be managed and be satisfied. More on how this affects the business model is presented in Chapter 7.

The Business Model Canvas			Actor **Aggregator-Prosumers**	
Key Partners	**Key Activities**	**Value Proposition**	**Customer Relationships**	**Customer Segments**
Prosumers DSO TSO Energy supplier	Energy management Market bidding Microgrid creation Energy consumption Reduce environmental impact Time-of-use optimization Self-balancing	Transparency of sales Security Sale of electricity Lower electricity prices Improve efficiency Self-sustainability/be green Cost saving Higher gains from DERs	Energy services Collaboration (B2B)	Other prosumers Producers Consumers BRP Supplier DSO
	Key Resources Energy management tool Distribution network Electricity to cover the imbalance of the system ICT platform DERs		**Channels** Existing grid ICT infrastructure Smart meters	
Cost Structure Costs of producing energy Electricity purchased from market Operational costs Maintenance costs Investment costs		**Revenue Streams** Selling excess electricity Energy saving Markets (e.g. flexibility)		

Figure 6.4: Business Model Canvas Prosumer in the Aggregator Role

6.2.2 Value Proposition Canvas

This section shall focus on providing the three VPCs resulting from the three innovated BMCs. This to further research the value propositions the blockchain offers to the innovated business models and thus the actors. The VPCs shall be used to examine how the blockchain intends to relieve the pains and create the gains of the customers. In the following the VPC of the DSO, Supplier, and the Prosumers in a local energy system providing a decentralised local energy market is presented.

First, the VPC of the DSO in the aggregator role is provided in Figure 6.5. Assessing the fit between the gains creators and gains we find a strong correlation between the two suggesting to be a strong fit. The blockchain platform shall provide flexibility to the DSO, likely improve customer satisfaction, positive PR and likely provide a more sustainable alternative. Next, considering the pain reliever component, we find a direct relation with regards to the pains of the DSO. As the LES is to function as a sort of virtual power plant, it can be managed to function as a form of flexibility. Furthermore, the LES shall lower peak demands due to their own self-sufficiency reducing grid losses in the process. It is however unclear to which extent this is beneficial. Considering the changing landscape the smart grid shall have to deal with many more and likely bigger peak demands (for example due to EV charging) than can be relieved by the niche market that shall be the LES. Therefore, it is debatable how strong the fit is in this regard. However, from a business standpoint, this does not directly have to suggest that the value proposition for the DSO is weak. As mentioned the nature of the relationship between the two parties is subject to change. The gain for the DSO is furthermore not solely reliant upon the value proposition of the blockchain, but for instance also in the customer relationship segment of the BMC. This is however further discussed in Section 6.2.3.

The supplier VPC presented in 6.6 is at first glance similar to the VPC of the DSO, providing the same relieves in terms of flexibility and sustainability. Again this is to be expected considering the minimal changes in the roles they will fulfil. However, there are some changes that need to be discussed. First, in the pain and pain relievers, there is a clear discrepancy with regards to the VPC of the DSO. This exemplifies the difference in incentive between the two actors. As the role of the supplier is less related to the VPP characteristic of the LES the pain relievers and pains do not fit as well as those of the DSO VPC.

Looking at Figure 6.7 we find that the blockchain platform provides gain creators that fully cover the gains component on the right side of the VPC. The pain relievers to the identified pains largely address the needs of the prosumer. The investment costs related to being sustainable and independent are not directly mitigated. However, the market should provide the prosumer with notably higher return on investment due to the market mechanism provided by the blockchain platform and the increased efficiency of the system. This thus suggests a strong overall fit, provided that the blockchain technology is able to provide what it intends to provide and the implementation cost not to be too high. With regard to the blockchain-enabled prosumers, this VPC can also be viewed upon as the blockchain-enabled prosumers VPC. This would thus function as an addition to the BMC provided in the previous section. This further exemplifies the potential the decentralised local energy market offers to the prosumers.
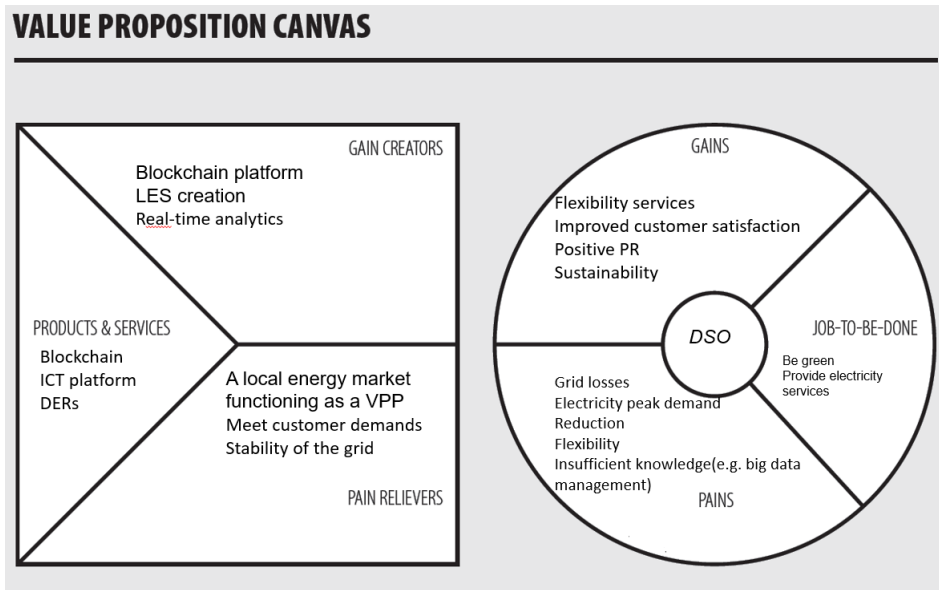
Figure 6.5: Value Proposition Canvas DSO
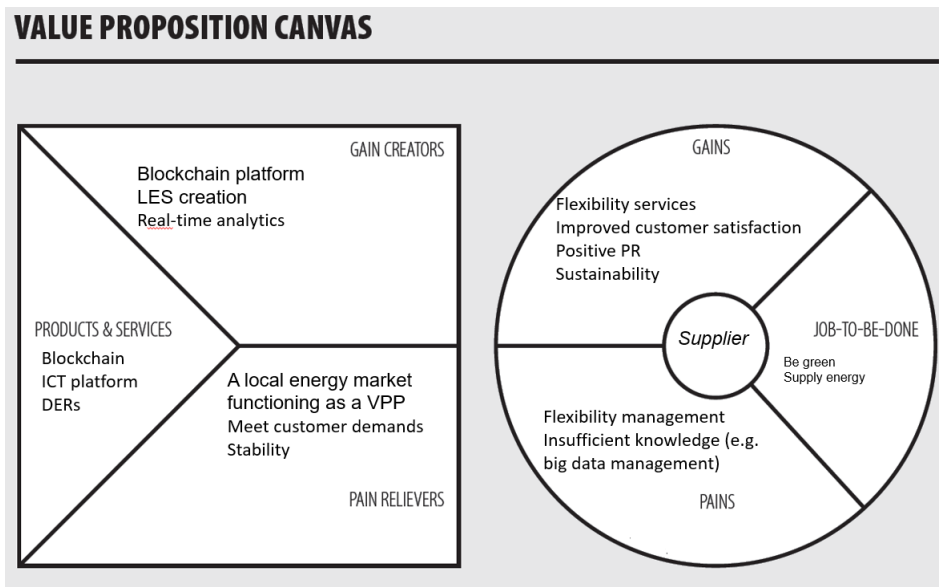
Figure 6.6: Value Proposition Canvas Supplier
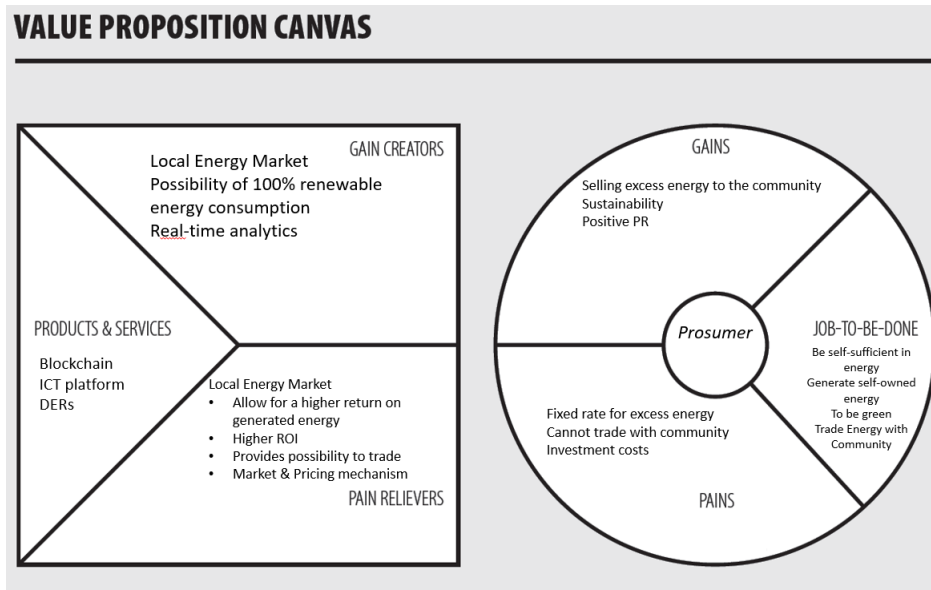
Figure 6.7: Value Proposition Canvas Blockchain-Enabled Prosumer

6.2.3 Loyalty to Empowerment

Following the BMCs and the VPCs, it can be deduced that the manner in which the customer relation between the DSO and the prosumers has traditionally been set-up has to alter. Generally, the customer relationship is based and marketed on the maintaining the customers and relying on their customer loyalty. This thus means the business' activities focus on creating loyal customers. However, there is a strong argument to switch the focus from loyalty towards empowerment, which is furthermore also argued by Olkkonen et al. (2017). In this research, one of the main findings was that the attitude of the traditional actors towards prosumers highly affects the way prosumers use their self-generated energy. In this context, the partnership shall be one that is more based upon collaboration and shall entail benefits not only for the DSO or the Supplier, but also the blockchain-enabled prosumers. This is among others due to their increased control over their energy consumption as a community. Besides, business models and product developments nowadays rarely fully follow the traditional S-curves of customer adoption and optimisation of the product. Business model innovation is a continues process as proposed by Heikkilä et al. (2015) and depicted in Figure 6.8 and should thus be treated as such. This would in turn increase the flexibility of the business model.
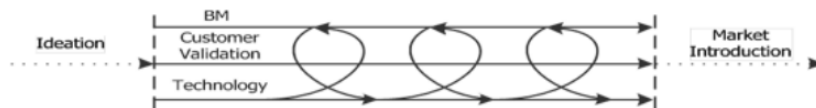
Figure 6.8: Business Model Innovation retrieved from Heikkilä et al. (2015)

It is important and must be noted that the technology driving the business models is of disruptive nature, and to define what exactly this means to the market. Christensen and Raynor (2013) describe sustaining innovation as 'something that targets those demanding, high-end customers with better performance than previously available'. Whereas the target of disruptive innovation is to provide not something that works better but something that is simpler, more convenient and less expensive than existing items. Although the term disruptive implies a sudden change in environment it is important to

understand that the innovation, like any innovation, takes time and is a process. Like any innovation, the process shall begin as a(n) (small) experiment which may fail or succeed and move forward from there. Disrupters thus tend to not focus as much on getting the product or service right, but rather on the business model driving the innovation. This thus further exemplifies the need for a strong business model. Considering the fact that two out of three actors are incumbents of the industry, it is imperative for the incumbents to clearly communicate to their new business partners (blockchain-enabled prosumers) what the product/service intends to provide. In Figure 6.9 the theory is visualised. In this context, both the incumbents (DSO & Supplier) and customer are possible to explore this new market.(Christensen et al., 2015)
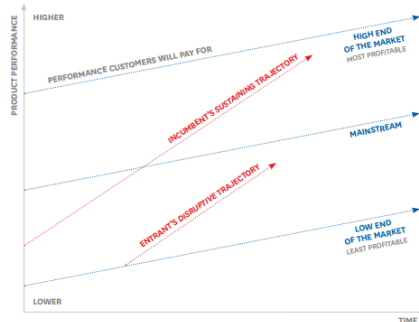
Figure 6.9: Disruptive Innovation model (Christensen et al., 2015)

Besides this traditional view of innovation, Christensen and Raynor (2013) proposed a new perspective for new customers and new contexts. This would be the domain in which the Prosumer would operate. In Figure 6.10 the new dimension is depicted. The third dimension extending towards us represents the new contexts of consumption and competition. These are referred to as value networks. This is defined as: 'the context within which a firm establishes a cost structure and operating process and works with suppliers and channel partners in order to respond profitably to the common needs of a class of customers' (Christensen and Raynor, 2013). Regarding the prosumers, this would entail that it is up to them to decide how the performance is measured and against whom they are competing. This is therefore something to keep in mind for decision makers in the future when considering to facilitate a decentralised local energy market, or to participate in one.
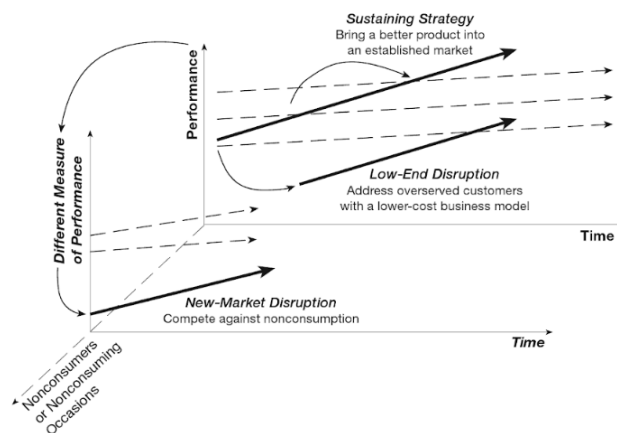
Figure 6.10: Disruptive Innovation model (Christensen et al., 2015)

6.3 Conclusion

In the following the answer to the fourth research sub-question, 'How may a blockchain facilitated local energy market be implemented in local energy systems?', shall be provided. By first reflecting on the local energy system energy value chain we found that the aggregator role is introduced and shall potentially disrupt the existing business models and provides new business opportunities. This role was found to be taken upon by one of three actors in this context: the DSO, Supplier and the Prosumers. This entailed providing three business models to assess their potential as well as a reference business model and a business model for the blockchain-enabled prosumers. Looking at the business model canvasses and value proposition canvasses of the actors it can be stated that the blockchain theoretically provides a strong fit with the value propositions for all three actors. This thus confirms that the role can be taken upon by either actor. However, as the BMCs and VPCs show, these would entail three different value propositions for each actor. In Table 6.1 these are provided along with the roles and responsibilities defined by Koirala (2017) to grant a clear overview.

Table 6.1: Value proposition & Roles of the Actors

Actor	Value Proposition	Roles & Responsibilities
Aggregator-DSO	Flexibility services, Improved customer satisfaction, Positive PR, Sustainability	Grid operation, local congestion management
Aggregator-Supplier	Flexibility services, Improved customer satisfaction, Positive PR, Sustainability	Supply energy deficit, management of local energy systems, flexibility & energy procurement
Aggregator-Prosumer	Selling excess energy to the people they know (neighbours), Sustainability, Higher return-on-investment	Consumption, payment investment, generation, energy management
Blockchain-Enabled Prosumer	Selling excess energy to the people they know (neighbours), Sustainability, Consumption, Higher return-on-investment, generation, energy management	End-user that provides the aggregator with flexibility

Considering the business models, we concluded that the proposed innovated business models are to be treated as a process. Business models are to adapt over time as the technology it is based upon evolves. This emphasised the importance of the changing relationship between the actors. Whereas the industry in this segment now works in a business-to-customer model there shall be a change towards a more business-to-business oriented industry as a result of the increasing empowerment of the prosumer.

7 | Stress Testing the Business Models

This chapter shall focus on the third, fourth, fifth and sixth step of the business model stress test. First, in Section 7.1 the selected uncertainties shall be mapped to the business model components. Second, the heat maps for the different business models shall be made in Section 7.2. Third, in Section 7.3 the heat maps shall be analysed to gain more insight as to how robust the business models are and where their weaknesses lie. These steps shall be performed in order to answer the sixth research sub-question: 'How robust are the innovated local energy market business models?'.

7.1 Mapping the Uncertainties to the Business Model Components

This section shall focus on mapping the uncertainties to the business model components. First, we look at the first technical uncertainty: Scalability. The scalability is directly related to the BM components: Customer Segments, Value Propositions, Revenue Streams, and Cost structure. The obvious components here are the value proposition, revenue stream and cost structure as the decentralised local energy market shall have to facilitate a minimum amount of participants in order to generate revenue, deliver the value proposition and in turn lower the cost structure. Firstly, considering the value proposition proposed in the VPCs alongside the BMCs we can state that these are highly dependable on the ICT capabilities of the system. A system that is not scalable shall thus devalue the proposition. This shall directly impact the revenue stream and costs structure as these are based on the return on investment, usage fees and the act of performing the key activities among others (Osterwalder and Pigneur, 2010). Furthermore, as suggested by O'Dwyer and Malone (2014) and Beck et al. (2016) the scalability issues will highly impact the sustainable nature of the proposition. A less obvious component is the customer segment. The customer segment shall be impacted due to the devalued value proposition. This is due to the fact that the value captured shall be lower as a result of this.

The second technical uncertainty Complexity is directly related to Value Propositions, Channels, Customer Relationships, Revenue Streams, Key Resources, Key Activities and Cost structure. The value proposition shall again be devalued in the worst-case scenario where the technology proves to be too complex, not allowing the system to solve the problem of the customer. As a result, this shall further impact the cost, revenue and key resources. A hard to manage system shall require more resources to manage and thus be more costly, less profitable and worth less in the intellectual resources sub-category of the key resources. A hard to manage system would furthermore affect the key activities of the BM to a lesser extent due to the increased need of attention. A less obvious component is customer relationship. The customer relationship is to a lesser extent affected by the complexity due to the intended automated work-flow of the system. However, if there is an expected higher downtime this might be something to take note of and shall thus indirectly affect the customer. Last, the Channels component could also be affected due to a high degree of complexity. This could entail issues like delivery of the energy and lack of understanding of the system. The latter would imply the value proposition to not be delivered to the customer and thus not capturing its full potential.(Osterwalder and Pigneur, 2010)

Second, the economic uncertainties: Energy Cost and Cost of implementation. O'Dwyer and Malone (2014) and Lund and Münster (2006) exemplify the significant contribution the blockchain shall have to the cost of energy that shall be sold. The energy cost is therefore mainly related to the revenue/cost components. As these in turn directly impact the Value proposition, for reasons like mentioned for the scalability and complexity uncertainties, this component is also related to the energy cost uncertainty. Furthermore, the uncertainty can be linked to the Customer Segments, Customer Relationships and Key Partners. The customer segments and Customer relationship are based on the value proposition and the degree of value creation that shall be realised. A more negative outcome (devalued value proposition) shall negatively impact these components. The Key partners are still actors to be taken into consideration in this context and shall among the traditional partners also be the prosumers. As they intend to get the most (cost) efficient system this business model component is thus also affected. However, in the case of the Prosumer business model the Key partners are of no influence as they do not have any interest in the energy price within the LEM.

The Cost of Implementation is highly related to the business model components: Cost structure, Revenue Streams and Key Resources. As the system shall require a significant investment it is debatable to what extent the local energy market is profitable. However, the value of the system is not just expressed in money, the intellectual resources are likely significant as well as the system itself and the knowledge required to build such a system is valuable. Next, the customer segment and relationship are affected as the costs shall reflect in the margins and the manner in which the service is facilitated. This thus further also affects the Value proposition.

Third, the first social uncertainties: Privacy. Logically this uncertainty is closely related to the Customer Segment and Customer Relationships. This uncertainty revolves around the upcoming regulations concerning the smart grid and the blockchains ability to handle the data in a secure manner which is in compliance with the regulations (Voigt and Bussche, 2017). If these requirements are not met this thus logically affects the aforementioned business model components. Next, the Key Activities is subject to the scenarios of the privacy uncertainty. If the system is unable to comply it shall not be able to perform the key activity of the system. This thus also directly impacts the revenue stream and the value proposition.(Schwieters, 2016)

Last, the second social uncertainty Adoption is left to be discussed. An unwillingness to adopt the system shall logically influence Customer Relationships. It is therefore of importance that there shall be a well 'designed' socio-technical environment. As stated by Stigka et al. (2014) there are still many unknowns as a result of the transitioning energy domain and there are many variables influencing it. As aforementioned BM components shall contribute positively to most components adhering better to the customers. Furthermore, due to this, the Channels component shall likely not be able to be made use of to its full potential. Logically the key activities shall be affected by the willingness of adoption. This shall in turn reflect in the revenue streams and a higher costs structure due to a need to invest more resources.

7.2 Business Model Stress Test

In the following, the results of the stress tests shall be provided for the DSO, the Supplier and the Prosumer. Per cell, there shall be provided with an explanation to the resulted colour. First, the generated heat signatures and impact reasoning are provided. These were graded following the findings of the aforementioned data gathered from the questionnaire and the literature reviewed in the previous chapters. The questionnaire is furthermore provided in Appendix B. Second, in Sections 7.2.1 the DSO and Supplier results are discussed. Third, the results of the Prosumer are discussed in Section 7.2.2.

7.2.1 DSO & Supplier Heat Signature

Chapter 6 has shown that the business models and VPCs of the DSO and Supplier are largely similar and as the scenarios will impact these two actors similarly. Figure 7.1 provides the heat signature of both actors in one heat map. As depicted on the heat maps each cell was given a cell code. In Table 7.1 the cell codes which are impacted are linked to the reasoning. The remaining cells that are coloured grey are explained and provided in Appendix A as these are less relevant to the research.

DSO & Supplier	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Value Propositions	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Channels	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Customer Relationships	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Revenue Streams	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Key Resources	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Key Activities	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
Key Partners	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
Cost structure	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12

Figure 7.1: Heat Signature of the DSO Business Model

7.2.2 Prosumer Heat Signature

Figure 7.2 depicts the heat signature of the prosumer business model. In the following, the scores shall be elaborated upon following the scenarios of outcomes.

Prosumer	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Value Propositions	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Channels	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Customer Relationships	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Revenue Streams	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Key Resources	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Key Activities	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
Key Partners	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
Cost structure	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12

Figure 7.2: Heat Signature of the Prosumer Business Model

The prosumer business model stress test results do not vary much from the DSO and Suppliers business models and thus only the discrepancies shall be provided in Table 7.2. The remaining cells that are coloured grey are explained and provided in Appendix A, as these are less relevant to the analysis. In the following section, the results of the heat maps shall be discussed to elaborate on the provided outcomes.

Table 7.1: Impact Reasoning DSO & Supplier Business Model Stress Test

BM Component	Argument
Customer Segment	
A1	Low scalability implies the system to not be able to serve the customer segment.
A2	Implies the customer segment is served. Furthermore, it allows the business to expand.
A5	Increases customer satisfaction, likely to result in a bigger market share as a result of increased economic incentive.
A6	Customer segment likely only wants to partake if the tariff is lower than the current tariff.
A7	Provides incentive to participate in the local energy market. Increases customer satisfaction
A8	The high cost of implementation is considered a key issue as it deters the value proposition to be delivered to the customer.
A9	Customer segment shall not accept a system that does not comply with regulations.
A10	Ensures the system to handle personal data securely serving one of the basic needs of the customer.
Value Proposition	
B1	Cannot deliver value proposition to the customer if the scalability poses to be an issue.
B2	Will directly impact the value proposition as the system can function as intended in terms of scalability.
B3	Will result in a potentially weaker value proposition for the customer, Value proposition might have to be reconsidered by the actor.
B4	No issues in delivering the value proposition to the customer.
B5	Increases the value of the proposition as it fulfils one of the main demands of the customer, namely: a lower energy tariff.
B6	Value proposition shall be heavily impacted and likely result in a showstopper as a result of a lack of economic incentive.
B7	Increases the value of the proposition as it fulfils one of the main demands of the customer, namely: low investment cost.
B8	Value proposition shall be heavily impacted and likely result in a showstopper. The cost of implementation is however subject to many factors like the economy of scales and technological advancements.
B9	If the blockchain is not able to provide a system that shall comply with the regulations there is no value proposition to be delivered.
B10	Increases the value of the proposition as it fulfils one of the main demands of the customer, namely: a highly secure energy system.
Channels	
C3	Hinders the evaluation of the progress and performance.
C4	Allows for proper evaluation of progress and performance.
C11	Impossible to reach the customers and provide needed information regarding the market (e.g. average energy tariff).
C12	Implies good communication with customer/collaborator
Customer Relationships	
D3	Due to the change in customer relationship a hard to manage system could prove to require specific attention leading to more resource spend.
D4	Synergy among the actors is envisioned as the system serves all actors according to their needs
D5	Implies value proposition is delivered well, will result in better relationship
D6	If intended tariffs are not met this will heavily impact the customer relationship

D7	Implies value proposition is delivered well, will result in better relationship
D8	If intended costs are exceeded this will heavily impact the customer relationship
D9	Non-existent as the system shall not be feasible due to regulations.
D10	Implies value proposition is delivered well, will result in better relationship
D11	An unwillingness to adopt shall hinder the relationship and collaboration among the actors.
D12	Implies relationship to be benefited from the implementation of the system

Revenue Streams

E1	Low scalable system shall lower the return-on-investment as the market is limited in size and thus investment costs shall relatively be higher.
E2	Revenue stream has the possibility be exploited in the future leading to a higher ROI.
E3	The complexer the system the more resources it requires and thus negatively affects the revenue stream
E4, E5 & E7	Favourable revenue stream to be generated in this scenario delivering value proposition to the customer.
E6	The revenue stream is slightly impacted however still generated. To what extent is to be determined.
E8	The higher the implementation costs the more the revenue stream is affected leading to a possible showstopper scenario.
E9	No ability to generate revenue if the system is not in compliance with regulations.
E10	Allows for revenue stream to be generated due to compliance with regulations.
E11	No customer base equals no revenue stream to be generated.
E12	Considered to be key to provide a customer base and thus a revenue stream.

Key Resources

F3	A hard to manage system requires a higher amount of resources. This could prove to be too costly.
F4	Adds to the (intellectual) resources increasing the intrinsic value of the platform.
F7	Require same key resources to be invested, up to decision makers
F8	Shall negatively impact the physical resources lowering the value of the platform.

Key Activities

G3	A higher degree of complexity requires a more from the activities of the business. The balance could negatively affected with respect to the gains.
G4 & G10	The system does not hinder the key activities and allows value capture
G9	Implies no actions can be taken
G11	Unwilling customer base shall make it impossible to perform key activities.
G12	Allows the business to perform all activities to its full extent.

Key Partners

H5	Value proposition of the actor partially reflects on the key partners as there are theoretically higher margins to be taken advantage of.
H6	Higher tariff implies lower margins to be made profit off.

Cost Structure

I1	Acquiring resources in this scenario is likely more costly as the customer pool is lower and thus costs are relatively high.
I2	Allows for economies of scale to take place lowering the average cost structure per participant.
I3	The cost of performing the key activities shall likely rise as a result of a need of more physical resources.
I4	Lowers cost structure as it requires less key resources.
I5	Might hurt the costs structure as margins go down and thus costs increase relatively.
I6	Implies there is more funds to be invested into reaching customers and maintaining relationships leading to a higher cost structure.
I7 & I8	Cost may prove to be too high no matter the investment, needs further research.
I11	May prove impossible to attract customers to create revenue. This increase the cost structure burden.
I12	Larger customer base implies relatively less costs per customer.

Table 7.2: Impact Reasoning Prosumer Business Model Stress Test

BM Component	Argument
Channels	
C3	Heavily hinders the evaluation of the progress and performance. Shall burden the Prosumer greatly.
Customer Relationships	
D11	Non-existent as the system shall not be feasible.
Revenue Stream	
E1	Due to limited scalability revenue stream cannot be established.
E6	A higher tariff would entail that the business shall technically costs revenue. However, it is to be researched whether this outweighs the business opportunities.

7.3 Analysing the Heat Maps

This section shall provide the analysis on the presented heat maps. In Section 7.3.1 the analysis shall be performed from the BM components sub-view. Similarly, the sub-view analysis of the uncertainties shall be performed in Section 7.3.2. The heat maps shall then be analysed for patterns in Section 7.3.3. Last, in Section 7.3.4 the heat maps are compared to each other.

7.3.1 Sub-View Analysis: BM Components

By analysis the sub-view on the rows of the heat map an idea of the robustness can be formed of each of the individual business model components. In the following, the heat maps shall be discussed.

DSO & Supplier

Figures 7.3 shows that the revenue streams component is impacted for every uncertainty and has three possible show-stoppers. Furthermore, the cost structure shows the same number of yellow areas in other cells but four possible showstoppers. This suggests that the idea of making a profit off of the LES is subject to quite a number of factors and scenarios. With regard to the DSO, this might suggest that considering decentralised local energy markets as a means of staying relevant is one that brings forth considerable risks. Furthermore, decision-makers should consider how much the green image and positive PR can be exploited and how much this is worth to the company.

Other components that stand out are the Customer relationship and Customer segments components. These both show three possible show stoppers. This shows that the customer is highly affected by most negative scenarios of the uncertainties. This is to be expected as the decentralised LEM is to function in close collaboration with the participants of the LEM.

Last, the value proposition has four areas that are marked red. This is a potentially alarming discovery as the value proposition, as provided in Section 6.2.2, is to be designed to the needs of the persona. Considering the fact that Chapters 3, 4 and 5 are focussed on providing a strong value proposition this would suggest that if the proposed system is not functioning as the literature suggests, the value proposition is likely worthless at this moment. In other words, in order to ensure value capture, the value proposition shall have to be guaranteed. This is however only possible by experiments and real-life application.

DSO & Supplier	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments												
Value Propositions												
Customer Relationships												
Revenue Streams												
Cost structure												

Figure 7.3: Business Model Components Sub-View of the DSO & Supplier

From this, we can conclude that the business models for the DSO and Suppliers perspective is such that the two actors shall have to make a trade-off when considering a market entry into decentralised local energy markets. This would, on the one hand, be to provide the customer with an alternative to the traditional/smart grid and in the process gain the benefits of doing so and on the other hand, face the risks that come with disruptive innovations which shall mostly apply to the Cost structure, Revenue stream components and Value proposition.

Prosumer

Figure 7.4 depicts the business component sub-view of the Prosumers heat map. This map shows the amplified risks with regards to the revenue streams component having five showstoppers and a yellow marked cell. Again, considering the fact that the value proposition is pre-designed this marks the need for a further research into the scalability, costs and potential regulatory issues local energy markets might put forth.

It must be stated that the business model in general is less robust than the previous two business models having more possible show-stoppers, less robust business model components and more possible negative effects. This is to be expected considering the fact that the prosumer would be a new player in the market and shall have fewer customers to make a profit off of. Section 7.3.4 shall further examine this.

Prosumer	Technical				Economic				Social			
	Scalability		Complexity		Energy Costs		Cost of Implementation		Privacy		Adoption	
	Negative	Positive	Hard to Manage	Manageable	Below Current Tariff	Above Current Tariff	Low	High	Regulatory Issues	In compliance with Regulations	Unwilling	Willing
Customer Segments												
Value Propositions												
Customer Relationships												
Revenue Streams												
Cost structure												

Figure 7.4: Business Model Components Sub-View of the Prosumer

7.3.2 Sub-View Analysis: Uncertainties

Like the previous analysis, a sub-view of the uncertainties shall provide an idea of the impact the individual uncertainties have on the business model. By selecting the scenarios in which there are the most yellow and red cells we find the scenarios that will prove the hardest to sustain from a business perspective. In the following, these shall be discussed per actor.

DSO & Supplier

As depicted in Figure 7.5 the sub-view consists of four weak scenarios and two scenarios that require attention. The most vulnerable parts of the business model are in the scenarios where the costs (of implementation) and the gains (due to a lower tariff) prove to be too high or too low respectively. Furthermore, in the 'negative' scenarios of the privacy and adoption uncertainties, the business case logically cannot be made. All of these scenarios affect at least four of the business model components

proving the significance of these scenarios. In order to avoid an infeasible business model, the actors should anticipate these scenarios mitigating these risks. For instance, experiments can be run to assess the price of energy traded in the LEM, the regulations can be further examined and surveys can be held to provide a perspective on the potential customer pool.

The hard to manage complexity, high energy cost and high cost of implementation scenarios are all potentially vulnerable parts of the business model. However, in conjunction with the recommended scalability experiment the complexity and energy costs can be assessed. The high implementation costs are a point of discussion that should be held by decision-makers of the respective parties.

DSO & Supplier	Technical		Economic		Social	
	Scalability	Complexity	Cost of Implementation	Energy Costs	Privacy	Adoption
	Negative	Hard to Manage	High	Above Current Tariff	Regulatory Issues	Unwilling
Customer Segments	yellow	gray	red	red	red	gray
Value Propositions	yellow	red	red	red	red	gray
Channels	gray	yellow	gray	gray	gray	red
Customer Relationships	gray	yellow	red	red	red	yellow
Revenue Streams	yellow	gray	red	yellow	red	red
Key Resources	gray	yellow	yellow	gray	gray	gray
Key Activities	gray	yellow	gray	gray	red	red
Key Partners	gray	gray	gray	yellow	gray	gray
Cost structure	yellow	red	gray	yellow	gray	red

Figure 7.5: DSO & Supplier Stress Test Sub-View Uncertainties

Concerning the other nine uncertainty scenarios, we find that there are six scenarios in which the business model will prove to be robust and three scenarios that shall require attention but are likely not show-stoppers. This implies the business model to be robust in the case of positive scenarios but stresses the importance of assessing the identified weaknesses.

Prosumer

As depicted in Figure 7.6 the sub-view consists of five weak scenarios and one that requires attention. It shows a high dependency on the regulatory constraints and willingness of adoption that the local energy market shall have to deal with as all boxes are indicated as possible show-stoppers. The costs are as expected a major point of attention. The complexity and scalability are less vulnerable but still prove to be affected in many business components if the negative scenarios are applied.

Prosumer	Technical		Economic		Social	
	Scalability	Complexity	Cost of Implementation	Energy Costs	Privacy	Adoption
	Negative	Hard to Manage	High	Above Current Tariff	Regulatory Issues	Unwilling
Customer Segments	yellow	gray	red	red	red	gray
Value Propositions	yellow	red	red	red	red	gray
Channels	gray	red	gray	gray	gray	red
Customer Relationships	gray	yellow	red	red	red	red
Revenue Streams	red	yellow	red	red	red	red
Key Resources	gray	yellow	yellow	gray	gray	gray
Key Activities	gray	yellow	gray	gray	red	gray
Key Partners	gray	gray	gray	gray	gray	gray
Cost structure	yellow	red	red	red	red	red

Figure 7.6: Prosumer Stress Test Sub-View Uncertainties

To conclude, the business model identifies three main concerns of which two are within the social category, namely: costs, regulations and adoption. This implies the business model of the prosumer to not be under much stress due to the addition of the blockchain technology to the local energy markets, but more on the regulatory issues and costs that are related to the implementation of the system. Furthermore, the adoption of the traditional actors of an aggregator role is to be researched as this is found to be a showstopper for all relevant business components.

7.3.3 Pattern Analysis

The pattern analysis shall provide an analysis of the coloured cells of the heat in order to identify the consistency and inconsistency of business model components with regard to the colouring and to identify preferred outcomes of the business model for all actors.

The heat map shows that there are no scenarios in which the business model is not robust as there are no business model components that have provided a double red rating for both scenarios. This thus means there are no components that shall have to be redesigned or reconsidered as a whole (e.g. the revenue model). In terms of consistency, it can be noted that the revenue streams component is affected by all uncertainties under all scenarios. This is thus something to take note of for future decision makers. Another consistency is the lack of impact on the Key partners component for the heat map of the Prosumer. This exemplifies the fact that the decentralised local energy market would be an independent business venture.

7.3.4 Cross-Comparing the Heat Maps

As the stress test was performed for multiple business models, which is uncharacteristic for the business model stress test methodology, there has been added an extra step to the process in order to provide a better answer to the research questions.

From the sub-view analyses, we find that for the DSO, Supplier and Prosumer the business models are most critical with regard to the scenarios concerning the costs and revenue and the actual delivery of the value proposition. It must be stated though that where the Prosumers business model is most affected by the revenue generated, the DSO and Supplier are more evenly affected across the different business model components. With regards to the case where the value proposition cannot be captured, the prosumers business model is rendered infeasible. The costs shall be too high and the revenue stream is highly affected due to this. This shall result in a situation where the prosumer is better off investing in other sustainable projects. In contrast to this, the DSO and Supplier are more reliant upon the customers relationships, the costs and generated revenue. By focussing more on the customer, the DSO and Supplier can tailor their value proposition. The pattern analysis further provided the conclusion that the business models do not need redesigning in any particular component of the business model.

To better understand how the business model is impacted by the blockchain we provide a visual representation of the DSO & Suppliers business model canvas in Figure 7.7. As depicted the business model is mostly impacted in the Cost structure and Value proposition components of the business model. Furthermore, the lesser impacted components are the Revenue streams and the Customer Relationships and Segments. These were found to be under pressure from the threats of regulation issues, unwillingness to adopt and scalability.
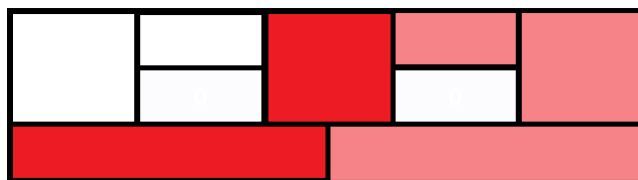

Figure 7.7: Overview of the Impact on Business Model Canvas Components DSO & Prosumer

Figure 7.8 depicts the impacted business model components for the Prosumer. For this business model, the main concerning areas are the Value Proposition, the Customer Relationships, the Revenue Streams and Cost structure. As the Prosumer is more vulnerable to the environment in which it operates it is to be expected that the relationship with the actors of the grid is of more importance than for the DSO and Supplier. Furthermore, as the Prosumer is less powerful and has fewer resources it is to be expected that the revenue streams are of more significance to the actor.
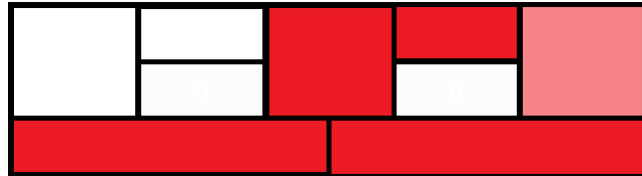
Figure 7.8: Overview of the Impact on Business Model Canvas Components Prosumer

From the cross-comparison, we can deduct that in either model the actor shall have to assess what exactly their intend to gain from the venture. As provided all models have possible show-stoppers or negative impacts on the Costs and Revenue components. Considering the need for the DSO and Supplier to soon be acting as a flexibility provider there shall have to be made investments in this department regardless. Moreover, a business venture like building local energy systems is one that shall greatly polish the image of these actors. To consider the trade-off between the costs and benefits is however up to the decision makers. With regard to the Prosumer, we found that there are more pressing issues than making money. Considering the value proposition it is likely an infeasible venture if the system turns out not be scalable or provide lower energy tariffs. Although the theory suggests otherwise, this still has to be experimented on and is thus considered a major weakness. The Customer Relationships is like the heat maps of the two other actors a weakness but for the prosumer more critical. In my opinion, this is however something that in practice might turn out to be more favourable than the literature suggests in contrast to the blockchains theory.

7.4   Improvements & Actions

This section shall provide the last step of the business model stress test methodology: the recommended improvements and actions to the business models.

7.4.1   DSO & Supplier

From the analysis, we can clearly deduct that in order to mitigate the risks involved there are three actions to be performed. First, in order to examine the extent to which there is a need for local energy systems, there shall have to performed market research. This will allow the DSO and Supplier to generate a better idea of how large their potential customer pool shall be, what they exactly want and expect from a local energy system/market and identify opportunities and threats as a result of these gatherings. Moreover, this will provide insight into the relative costs that shall go into this business venture, potential profit to be made and allows for the making of a business strategy. Second, the upcoming regulations shall have to be further examined. Although the blockchain, in theory, provides the needed functionalities there should also be an extensive assessment regarding how feasible it actually is to comply with the regulation. This however is a question that is not so much about decentralised local energy market but (local) energy market in general. Third, there shall have to be set-up experiments running decentralised local energy market to examine the true scalability of the system. This in turn shall provide a clearer overview of the costs and profits that are to be made and assess the degree of value capture that can take place.(Dodgson et al., 2013)(Mahajan et al., 1991)

7.4.2 Prosumer

Considering the fact that the heat map of the Prosumer is even more critical than those of the DSO and Supplier the aforementioned three recommendations also hold for the Prosumer. However, as the prosumer is a far less powerful actor in the energy domain it is likely infeasible to perform an experiment to test the scalability. As the customer segment is clear, the regulations are left to be examined. As the value proposition is the major impacted business component, which is heavily affected by the scalability of the system, this thus suggests that the business case for prosumers is at this moment infeasible. However, following the theory of Rogers (2010) it can be argued that the prosumers market entry is better placed in the early adopters segment of the adoption curve, which places them outside of the research and development category regardless of the feasibility to develop. In Figure 7.9 the adoption curve and S-curve are presented, despite the earlier mentioned flaws of the theory in this day and age this still is a useful tool when considering market entry and can be utilised by both the prosumer as well as the DSO and Supplier.(Dodgson et al., 2013)(Mahajan et al., 1991)
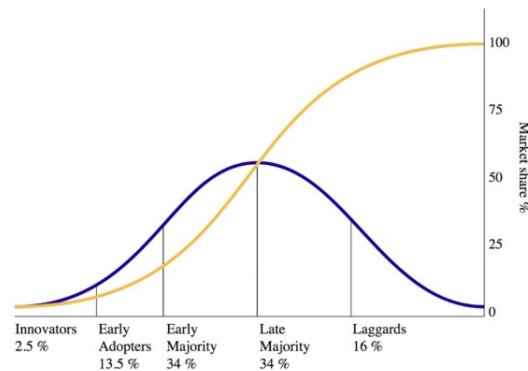
Figure 7.9: Overview Impact on Business Model Canvas Components Prosumer

Aside from the three actions, the prosumer is advised to undertake before market entry, one more action is advised, namely: to incentivise parties. If the DSO and Supplier are not to be endeavouring in local energy markets then the Prosumer shall have to incentivise them to cooperate. This could also lead to investments making their business model more robust and less vulnerable to the costs which have proven to be possible show-stoppers.

7.5 Conclusion

This chapter has provided the heat maps resulting from the stress tests as well as the analyses of the business models based upon the results of the stress tests. First, the uncertainties were mapped to the business model components. Second, the data collection and strategy was provided followed by a presentation of the heat maps and an elaboration on their colour gradings. This made the analysis of the business model possible, which was performed following four different approaches: sub-view analysis of the business model components, sub-view analysis of the uncertainties, pattern analysis and a cross-comparison of the business models. These steps were performed to answer the sixth research sub-question: 'How robust are the innovated local energy market business models?'. In the following, the answer to this question shall be provided.

Concerning the business model of the DSO and Supplier, we found that that the blockchain mainly impacts the business model components related to the customer, value proposition and the revenue and costs. This largely is contributed to the uncertainties: Cost of Implementation, Energy Costs and Privacy. This resulted in a proposal of three improvements and actions. First, a market research to map the potential customer pool, required investment and possible profits to be made. Second, an assessment of the regulations that need to be met and if the system is to comply with these regulations. Third, an extensive experiment assessing the scalability and energy consumption of the decentralised local energy market.

Considering the Prosumer business model, we found that like the previously discussed business models the vulnerability is located at the Customer Segment. However, the more critical weaknesses lie in the Customer Relationships, Cost structure, Revenue streams and Value Proposition components. The latter is one of main concern as it is an inherent property of the proposed system and has been designed to meet the needs of the users. Again the main problematic uncertainties are (indirectly) scalability (which influences energy costs and implementation costs) and privacy. Considering the significantly lower power the prosumer holds within the industry the proposed experiment was considered to be less viable/infeasible and therefore a market entry is considered to be infeasible at this moment. In order to make a market entry at a later stage, which is advised, as an 'early adopter' the action of incentivising parties was made in addition to the three aforementioned actions.

8 | Conclusion, Discussion & Recommendations

This chapter shall first provide the conclusion to the research answering the main research question as well as the research sub-questions. Second, a discussion on the assumptions made, limitation of the research and academic, managerial and social relevance of the research is provided. Third, the relation to the Management of Technology programme is given. Last, the recommendations for future work are proposed.

8.1 Conclusion

In Chapter 1 the main objective of this research was provided, which was defined as follows: 'to identify the impact of the blockchain on the business models of the actors considered to take upon the aggregator role in order to facilitate local energy markets'. Following the research objective the main research question was formulated, which is as follows:

'How does blockchain impact local energy markets business models?'

In order to fulfil this objective and answer the main research question, there was first conducted a literature review on the transitioning energy domain, local energy systems, local energy markets and the blockchain domain. As a result of the synthesis of these domains, a set-up of a decentralised local energy market was proposed. Following this synthesis, the trends within the energy domain and blockchain domain were analysed to provide six uncertainties within three categories. These were then further dissected into two possible scenarios for each uncertainty. The innovated business models for the DSO, Supplier and Prosumer were then stress tested. As a result of this, the main research question and the six formulated research sub-questions can be answered. This section shall focus on providing these answers. In the following, the answers to the research questions are provided.

SQ-1: 'What are the characteristics of local energy systems?'

In order to answer this question, there was conducted a literature review. This established the place and function of the local energy system in the transitioning energy landscape by defining the local energy system and proposing it as an adaption of the organised prosumer market model. Next, three characteristics of the local energy market were established, namely: Distributed Energy Resources, Energy Consumption, Energy Control System and Business Models. These characteristics cover the requirements of the smart grid and the local energy system as a sub-system of the smart grid.

SQ-2: 'What would be the key elements of local energy markets?'

Building upon the findings of the first research sub-question the notion of local energy markets was first defined as: 'a place in which prosumers, producers and consumers can trade locally produced renewable energy. This market, as the term suggests, is geographically constraint and has a distinct trading and pricing mechanism.'. This was followed by the identification of the key elements which are as follows:

Design, Information System and Market Mechanism. This resulted in a schematic design of the local energy market leaving a variable role for the aggregator, a proposed information system and market mechanism layout.

SQ-3: 'What is the value proposition of the blockchain with regard to the energy industry?'

In order to assess the value proposition of the blockchain first, there was conducted a literature review on the blockchain technology to establish the characteristics of the blockchain. This provided a definition of the blockchain technology by Swan (2015) which is as follows:'The blockchain is the decentralized transparent ledger with the transactions records – the database that is shared by all network nodes, updated by miners, monitored by everyone, and owned and controlled by no one. It is like a giant interactive spreadsheet that everyone has access to and updates and confirms that the digital transactions transferring funds are unique.'. Followed by the key architectural concepts: Distributed, Trustless, Secure, Immutable and Dis-Intermediating. In order to assess what the value proposition would be a more detailed approach to the consensus mechanisms was taken. Identifying the different type of blockchains and assessing them on their respective properties related to the energy industry. Next, some running blockchain projects have been shortly discussed to provide an idea of where the technology stands in terms of development and to further research the possibilities of the blockchain in the energy industry. Last, the most favourable blockchain was chosen. Ethermint was chosen in a permissioned private blockchain set-up. Ethermint runs on a Proof-of-Stake protocol based on a practical Byzantine Fault Tolerance consensus mechanism, making it a very efficient and fast blockchain. Especially considering more traditional blockchains like Ethereum. This allowed for an answer to the research sub-question which can be formulated as: the theoretical value of the blockchain to the energy industry is high. There are however some key issues that need to be addressed in order to capture the value proposition of the blockchain.

SQ-4: 'What are the uncertainties of using a blockchain to facilitate a local energy market?'

From the gathered answers to the first three research sub-questions now a synthesis of the energy domain and the blockchain domain could be performed. This synthesised the elements of the proposed local energy market with the functionalities of the proposed blockchain. It was found that the blockchain, although with some disadvantages, is able to facilitate a local energy market. This is, however, a purely technical statement which does not take the business science into consideration. Therefore, a trend analysis was performed to establish the trends in the energy landscape and more specifically those towards local energy communities. This to find the uncertainties needed to create the heat map template needed to perform the business model stress tests. Based on the findings of both the trend analysis and the literature review of the blockchain domain there were established three categories: Technological, Economic and Social. Each containing two uncertainties resulting in six most relevant uncertainties to the decentralised local energy market. In the following, these shall shortly be provided and elaborated upon.

Technology: Scalability
The scalability assesses the extent to which an LES can be scaled whilst being feasible. This takes up-scaling as well as down-scaling into consideration. The scaling of the market takes the ability of the blockchain into consideration with regards to throughput, finality and latency and as a result of a higher scale implementation the increase in these factors.

Technology: Complexity
The complexity refers to not only the use of the technology (e.g. management, maintenance, etc.) but also the unsolved challenges due to inherent characteristics of the blockchain or for instance its relative immaturity. This is especially relevant within the energy industry as there are but a few pilots running at the moment.

Economic: Energy Costs

The cost of energy refers to the price participants need to pay per KWh. The intent of the system is to provide the participants with a lower energy tariff than their current grid tariff. However, with the implementation of the LES and LEM, there are some significant factors to be taken into account like the blockchain. Due to the dedicated components needed to facilitate the LES and LEM the average energy consumption per participant is much higher than for normal households. On the other hand though, with the current proposed architecture of the LEM, the transaction costs are mitigated, energy is self-generated and there are no margin fees.

Economic: Cost of Implementation

The implementation cost speaks for itself. This is however a tricky uncertainty due to the fact that it is difficult to truly say what specific investments are towards a decentralised LEM as many of the technologies and investments are already being made due to the emergence of the smart grid (e.g. smart meters). Furthermore, as mentioned, it is debatable who exactly is to pay for these initiatives. Due to this, it is assumed that the costs of implementation are to be taken upon by the actor that is discussed in the respective business model.

Social: Privacy

Besides the regulations that the blockchain shall have to comply with, it is important for the local energy system to be at least as, but preferably (much) more secure than the current system. Therefore, this uncertainty can be considered to be both social as technological. The blockchain that is to facilitate the system shall need to be able to withstand possible attacks to the system at a performance where the participants do not question its ability.

Social: Adoption

The willingness of the participants is of great influence with regard to the robustness of the business model. In the changing energy landscape, it is furthermore the case that the participants are expected to be more involved. The adoption does not limit itself to just the adoption of new technology but also the willingness to be part of the energy industry in the role that shall have to be fulfilled as an aggregator or business partner.

In order to properly assess the impact of these uncertainties during the stress test, there were per uncertainties proposed two scenarios on each extreme side of the possible outcome spectrum. This finally resulted in the heat map template that was to be used during the stress tests.

SQ-5: 'How may a blockchain facilitated local energy market be implemented in local energy systems?'

In order to perform the stress tests there first had to be made three innovated business models. This due to the fact that the aggregator role was proposed to be taken upon by one of three actors, namely: the DSO, the Supplier or the Industrial/Commercial Prosumers. By providing the business models there could be identified how the decentralised local energy market was to be positioned and implemented in the transitioning market. To further elaborate on the models there were provided value proposition canvasses for all actors. The chapter further contained a reflection of the implications of the decentralised local energy market to the customer relationship and the ideal market entry of the system.

SQ-6: 'How robust are the innovated local energy market business models?'

In Chapter 7 the stress tests were performed and analysed. This provided the answer to the sixth research sub-question. For the DSO and the Supplier, it was found that the most critical weaknesses were in the Value Proposition and Cost Structure components with lesser critical areas identified as the Revenue Stream, Customer Segment and Customer Relationship. In contrast to this, the Prosumers most critical weaknesses were identified to be the Value Proposition, Customer Relationships, Cost

Structure and Revenue Stream. With lesser critical weakness at the Customer Segment. Resulting from these tests there was performed sub-view analyses on the uncertainties and business model components. Next, there were performed analyses focussed on identifying patterns and lastly, the business model heat maps were compared to each other. These analyses provided insight which was used to proposed improvements to the business models and recommend actions before considering market entry. These are threefold for the DSO and Supplier, namely: perform market research, research regulations and to perform blockchain experiments. The Prosumer is advised to undertake one more action, namely: to incentivise partners. Considering the significantly lower power the Prosumer holds within the industry the proposed experiment was, however, considered to be less viable/infeasible and therefore a market entry is considered to be infeasible at this moment and is advised, as an 'early adopter' at a later stage.

8.1.1   Answering the Main Research Question

This research provides the building blocks needed to facilitate the notion of a decentralised local energy market. By providing business models for the DSO, Supplier and Prosumer in the role of an aggregator, it was determined that both the DSO and the Supplier can be considered as 'innovators' to the market. The business opportunities for industrial and/or commercial prosumers are considered to be in later stages of the adoption curve, preferably as 'early adopters'. The business model stress tests provided an insight into the robustness of the business models and identified some of the vulnerabilities of the blockchain as a local energy market facilitator. These were however found to be manageable with respect to the technical feasibility of the DSO and Suppliers business models at this point. This can however not be said for the Prosumers business model as a result of their relative power in the market.

To conclude, this research has provided the initial assessment of the uncertainties and challenges that the blockchain brings to local energy markets and identified the most likely actors to successfully facilitate decentralised local energy markets. The concept of decentralised local energy markets has proven to provide a theoretically feasible business case with respect to the identified technological, economic and social challenges.

8.2   Discussion

In this section, there shall be provided a reflection on the assumptions made and the limitations to the research and the chosen methodology. Furthermore, the relationship of the research to the curriculum of the master Management of Technology is provided.

8.2.1   Assumptions

The business models that have been assessed are all based on the proposed decentralised local energy market. This proposal is however heavily based on the assumption that the (blockchain) technology delivers the functionalities as suggested by the theory. This is however a very strong assumption given the fact that we are dealing with a highly immature technology and innovations which shall have to be reiterated over time.

The business model stress test is furthermore based on the identified uncertainties. These uncertainties are however based on trend analyses which are projections of the future. This is however logically not a certainty and there might be sudden changes to the energy industry disrupting all of these trends. One can think of the emergence of WhatsApp which minimised the use of SMS.

8.2.2   Limitations

The first limitation is considered to be the exploratory nature of the research. Due to the immature technology that is involved, it is hard to estimate how it will impact the business model components.

This introduces the research to be susceptible to interpreter bias.

Second, due to the fact that this research is largely qualitative in nature and has been based on literature, secondary data and proposals there is a limited validity. This is among others due to the subjectivity involved in the proposed uncertainties and assessment of the business models. It is highly likely that there shall be different opinions among different experts in the field regarding some of the identified vulnerabilities of the business models. However, this is inherent to qualitative research, the focus group or experts that would provide judgement in large part are biased in some regard as well. For instance, it is very likely that a blockchain expert is positive about the potential of blockchain technology whereas an energy consultant might not be. This furthermore affects the replicability of the research which is considered to be low. A selection of different experts would likely results in different judgements towards the research. The external validity of the research was largely safeguarded however due to the fact that the research was not focussed on a specific area. For instance, there might be problems when transferring the research findings to a different context or setting.

Due to the nature of business models, the proposed models have a limited degree of complexity. It is practically impossible to capture the complexity of the entire industry into a few business model canvasses. Furthermore, the literature suggests that business models are to be seen as a continuous process and the model shall have to be iterated multiple times over a long period of time (literature suggests years over months). However the fact that the value proposition canvasses assist in providing a more elaborate overview of the environment, it can be stated that the business models are only representable on a conceptual level. This however does not take away from the findings of the research as the goal was to provide more guidance for future decision makers researching the potential of decentralised local energy markets.

The limitations of the business model stress test methodology are first of all the fact that it only considers the scenarios but not takes the likelihood of them happening into account. As the scenarios are at extreme ends of the spectrum this thus, in the author's opinion, will lead to unnecessary actions to be taken/recommended. It is therefore suggested that in future research there first is to be conducted a research on the likelihood of scenarios happening. Furthermore, the methodology recommends a low number of scenarios to be considered as the heat maps tend to get too complex and unmanageable. Considering this research, a lower number than six criteria was considered to be the minimum to cover the scope of this research. As a result of this, the heat map got so elaborate that experts were almost impossible to incentivise to provide judgement. As a result, the decision was made to limit the questionnaire to the 'negative' scenarios lowering the number of questions by 50%. Lastly, due to the low number of experts that have provided their input for the business model stress test the bias of input is considered high. As mentioned it has proven to be very difficult to get input from the experts and thus the questionnaire was designed with time restrictions in mind. This luckily resulted in a far higher response rate (12.5%) but also introduced a lower reliability of the results. Personally, I think that the methodology could very well function without the 'positive' scenarios. If the work that is put in these scenarios is put in researching the likelihood of the 'negative' scenarios I feel the result is much more valuable to the involved actors. This is however a conclusion drawn as a result of the use of this methodology and is thus said in hindsight.

8.2.3 Academic Reflection

This section shall reflect on the academic contributions to the four domains of this research, namely: the local energy domain, blockchain technology, business models and business model stress.

Considering the literature regarding blockchain facilitated local energy market this research contributes to the requirements that need to be met in order to successfully implement decentralised local energy markets. The characteristics and key elements can be made use of in future case studies and shall help identify the feasibility of the system.

As a result of the research, the literature on blockchain is extended as it provides more insight into the feasibility of blockchain as a virtual layer to local energy markets. The research furthermore contributes to the notion that blockchain is more than just a tool to enable dis-intermediation by the presentation of this use case. By exposing the strengths and versatility of blockchain, it shows how the energy industry can cater to the needs of the industry and its customers. In doing so an incentive is created for DSOs, Suppliers and Prosumers to participate in the development of blockchains for local energy markets.

The literature on business models is extended by an illustration of how blockchain can impact the local energy system business models. These models are largely based on literature and by incorporating insights gathered from the research the business models can be refined. The usability of the business model canvas model has been further proven as a result of the adoption of it for this research. However, it also identifies a number of flaws and areas of improvement with regards to the application of it in this area of research (blockchain and local energy markets). First, some business model components are deemed unnecessary to review in the context of decentralised local energy markets as they are not affected by the addition of blockchain to the grid. These have been identified to be Key Resources, Key Activities, Key Partners and Channels. In removing these from the canvas the heat maps shall shrink in size making them more manageable and be more focused. Second, the business model canvas fails to capture the addition of a blockchain as an enabling technology. This further exemplifies the need for additional context provided by the value proposition canvas and is thus recommended in future studies. In the following, this shall be further elaborated upon.

Reflecting on contribution to the business model stress test method used for this research, there were made four contributions. First, the use of the Business Model Canvas to map the business models contributes to the method as it proves the characteristic of allowing the use of interchangeable business model ontologies. Second, this research contributes to the method as it not only makes use of the business model canvas but adds the value proposition canvas. Further reflecting on this addition, it can be stated that it provides some needed feedback with regard to the context in which the business model is placed. Comparing the business model canvas to the STOF and CSOFT models, it was found that the business model canvas is lacking in providing context. Especially when considering the implementation of immature disruptive innovations, it is difficult to consider the STOF and CSOFT models leaving the Business Model Canvas to be the most suitable business model ontology. However, using the canvas will in turn simplify the context of the innovation, which is many cases is equally important. Therefore, the addition of the value proposition canvas contributes to the future use of the business model stress test and serves as a recommended addition. Third, the research contributes to the method by making use of the unconventional input via a questionnaire combined with literature and secondary data. Fourth, to the author's best knowledge, this is the first thesis that cross-compares heat maps resulting from a business model stress test. This contributes to the method as it proves to function as a manner to explore the feasibility of market entry for different actors.

8.2.4 Managerial Relevance

With the current transitions towards the smart grid the industry shall increasingly need to adapt to the technological disruptions. As blockchain has proven to be a high-potential technology able to disrupt the energy landscape, it is important to guide the incumbent actors as well as possible entrants in adopting this technology. This research provides insight in how actors can adopt to the changes in the customers needs with regard to their energy consumption and production. This is done by providing a blockchain solution that facilitates a local energy market.

Second, this research provides an insight into the local energy domain and provides information on how the value proposition can be captured. This is done by the provided business model canvasses and value proposition canvasses. In addition, the business model stress test is introduced. This method allows management to structurally and practically evaluate the robustness and vulnerabilities of the business strategies.

Third, this research helps managers and executives understand how the customer relationship can be affected by the implementation of disruptive technologies like blockchain and IoT. This reflects in the key activities of the actors as well as many other business model components as provided. Moreover, these insights are not limited to solely the considered industry.

Fourth, this research provides insight into the impact of blockchain on the robustness of local energy system business models. Recommendations formulated based on this evaluation help the considered actors to adapt their business models, strengthen their position and formulate strategies accordingly.

To conclude, this research aims to incentivise actors to adopt innovations and technology enabling sustainable energy generation. In addition to this social and environmental cause, there is a potential for enhancing operational efficiency that is not limited to blockchain-related innovations.

8.2.5 Societal Relevance

The societal relevance of this research mainly reflects in the positive implications it might have on developments towards a sharing economy. Blockchain theoretically provides a technological platform enabling societies to share their self-generated energy among each other. Considering the results of this research, blockchain has proven to affect many business model components (e.g. value proposition, revenue streams, cost structure). This will likely incline customer to adopt the notion of local energy markets and sustainable energy as a whole. In turn, this shall impact environmental issues like the production of CO_2, something that can only applauded.

8.2.6 Relating the Thesis to the Management of Technology Curriculum

This section shall provide the relationship of the research to the Master of Science programme of Management of Technology. The criteria for a typical Management of Technology thesis are defined as follows:

1. The work reports on a scientific study in a technological context (e.g. technology and strategy, managing knowledge processes, research & product development management, innovation processes, entrepreneurship);

2. The work shows an understanding of technology as a corporate resource or is done from a corporate perspective;

3. Students use scientific methods and techniques to analyse a problem as put forward in the MoT curriculum.

In the following these criteria as well as the relevant courses of the Management of Technology curriculum shall be related to the research.

First, the research considers the entrepreneurial and strategic decision making processes of the actors considered to facilitate the local energy market. This requires the understanding of the topics taught in the course Leadership and Technology Management (MOT1524) and Technology Dynamics (MOT1412). To elaborate, topics such as the alignment of technological innovation with the involved actors and to consider the drivers and barriers that have to be dealt with during the innovation and adoption process

are touched upon.

Second, the courses Technology, Strategy and Entrepreneurship (MOT14345) and Emerging and Break-through Technologies (MOT2421) helped to define the concept of local energy markets in terms of innovation. This entailed establishing maturity of technology which helped considering market entry feasibility, consider uncertain environments and how to manage them. The courses Inter- and Intra-Organisation Decision Making (MOT1451) and Social and Scientific Values (MOT1442) furthermore provided the knowledge to propose how to involve stakeholders and consider their values. Without these considerations, the concept of decentralised local energy markets cannot be considered as a feasible business case.

Third, the courses Research Methods (MOT2312) and Preparation MSc thesis for students studying abroad (MOT2003) helped me to define the requirements and methodology needed to establish a sound thesis structure.

Last, the courses Business Model Innovation and Entrepreneurship and Innovation Management that were taught to me during my time the Southwestern University of Finance and Economics in Chengdu were helpful as they provided me with the knowledge needed to make business models and innovate them.

8.3   Recommendations for Future Work

The limitations discussed in Section 8.2.2 allow us to provide suggestions for future work regarding decentralised local energy market.

Considering the wide range of subjects that have been touched upon in this research there is much to be further researched. Firstly, considering the local energy systems and local energy markets, the proposed architectures of the sub-systems and market can be researched into further detail. As this research was focussed on a business science approach and was largely focussed on business models and business model innovation there is much room to research the concepts from different disciplines. These would, for instance, entail market research, researching the market mechanism or research on current regulations.

Secondly, considering the blockchain domain the Ethermint blockchain can be coded and tested for usability. The blockchain can then be optimised and tested in an experimental environment. In such a set-up the scalability and energy consumption of the system could be further assessed filling in some of the limitations of the research. In doing so the business model stress tests will gain more validity. Moreover, the smart contracts involved can be set-up implementing the required policies needed to facilitate secure transactions.

Following the results of the analysis, we found that the customers to be of significant importance to the business models. Therefore it is recommended to further research the market and identify the possible customer pool. Interviews with prosumers, consumers considering to become prosumers and the actors within the current industry should be conducted to gain more insight. Furthermore, interviews with a large sample size are recommended to replicate the findings of this research.

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A - Justification Grey Cells Heat Map

Reasoning Grey Cells DSO, Supplier & Prosumer Business Model Stress Test

BM Component	Argument
Customer Segment	
A3 & A4	The customer segment has no benefit or disadvantage regarding the degree of complexity of the market. Therefore, it holds no relevant influence.
A11 & A12	The group of customers is not affected by their own (un)willingness to adopt the system.
Value Proposition	
B11 & B12	The value proposition still holds regardless of the willingness to adopt. It is the value capture that is affected by this uncertainty.
Channels	
C1 & C2	Scalability holds no influence over the channels component as it does not relate to the manner of which the organisation interacts with its customers.
C5 & C6 & C7 & C8	Costs logically do not affect how the customer is reached
C9 & C10	Regulations do not apply to how the customer is reached
Customer Relationships	
D1 & D2	The scalability of the system has no influence over how the organisation interacts with its customers.
Key Resources	
F1 & F2	The scalability of the system is not affecting any of the four categories of key resources
F5 & F6	None of the common categories are affected by the cost of the energy
F9 & F10	None of the four sub-categories of the key resources component is affected by a regulation or policy.
F11 & F12	None of the four sub-categories of the key resources component is affected by the willingsness to adopt the system.
Key Activities	
G1 & G2	The scalability does not affect the work an organisation has to perform to reach the customer or deliver the value proposition.
G5 & G6	The energy costs does not affect the work an organisation has to perform to reach the customer or deliver the value proposition.
G7 & G8	The implementation costs does not affect the work an organisation has to perform to reach the customer or deliver the value proposition.

Key Partners	
H1 & H2 & H3 & H4	The Key partners are not involved in the scaling of the system and thus have no influence over the technology of the system
H7 & H8	Implementation costs shall not be made by any of the key partners.
H9 & H10	The key partners are not involved in complying with regulations.
H11 & H12	The Key partners hold no influence over the customer with regard to their willingness to adopt and are not intended to do so.
Cost Structure	
I9 & I10	Considering the five sub-categories of the cost structure component there are none that are affected by compliance of regulations.

B - Questionnaire

In the following the questionnaire is presented.

Introduction

Dear Participant,

First of all thank you for taking the time to fill in this questionnaire.

The questionnaire shall consist of 33 multiple choice questions split up into six sections.

The questionnaire shall roughly take up 10-15 minutes to complete + 5 minutes of explanation (depending on your level of familiarity with business model canvasses).

The research is focused on assessing the potential of the blockchain technology to facilitate local energy market in a local energy system. This, among others, included the making of business models for the different actors that have been identified to take upon the role of facilitator of this notion of a local energy market. In order to assess the robustness of these models this survey is to be used.

The goal of the survey is to gain expert judgement on the impact of the blockchain technology on the business model components in different types of scenarios. These scenarios have been deducted from a trend analysis on the transitioning energy and blockchain domains. In the following section the theory of the business model canvas is provided to better understand the survey questions.

Your response will be kept strictly confidential, only members of the research team shall have access to the information you give.

Cordially,

Xavier de Vrij

Explanation

Note: It might be beneficial to copy the following information into a Word document to have quick access to the information if need be.

A "business model" is a high-level description of a business. One popular way of visualising a business model is via the use of a 'business model canvas' . The business model canvas consists of 9 components.

Explanation of the Business Model Components:

Customer Segments: are groups of people the organization seeks to serve.

Value Propositions: are the collection of product or services an organization provides to a customer segment.

Channels describe: where the organization reaches and interacts with its customer segments.

Customer Relationships: describes how an organization interacts with its customers.

Revenue Streams: are the sources of cash an organization makes from each Customer Segment.

Key Resources: are the most important assets an organization needs to deliver their value proposition.

Key Activities: represent the work an organization must perform in order to interact with their customers and deliver the Value Proposition.

Key partners: are the other organizations this organization relies on, or outsources to, to interact with their customers or deliver their Value Proposition.

The Cost Structure: represents all of the costs the organization will incur.

Questionnaire

All questions were posed as multiple choice questions allowing for the answers:

- Possible showstopper: needs attention from a strategy perspective
- Negative (or positive) effects cannot be excluded, but attention is required
- No negative effects are expected

Questions Survey:

1. How does a low scalable blockchain affect the customer segment for local energy markets?

2. How does a low scalable blockchain affect the Value Propositions for local energy markets?

3. How does a low scalable blockchain affect the Revenue Streams for local energy markets?

4. How does a low scalable blockchain affect the Cost structure for local energy markets?

5. How does a hard to manage blockchain affect the Value Propositions for local energy markets?

6. How does a hard to manage blockchain affect the Channels for local energy markets?

7. How does a hard to manage blockchain affect the Customer Relationships for local energy markets?

8. How does a hard to manage blockchain affect the Revenue Streams for local energy markets?

9. How does a hard to manage blockchain affect the Key Resources for local energy markets?

10. How does a hard to manage blockchain affect the Key Activities for local energy markets?

11. How does a hard to manage blockchain affect the Cost structure for local energy markets?

12. How does a higher energy tariff per KWh affect the Customer segment for local energy markets?

13. How does a higher energy tariff per KWh affect the Value Propositions for local energy markets?

14. How does a higher energy tariff per KWh affect the Customer Relationships for local energy markets?

15. How does a higher energy tariff per KWh affect the Revenue Streams for local energy markets?

16. How does a higher energy tariff per KWh affect the Key Partners for local energy markets?

17. How does a higher energy tariff per KWh affect the Cost structure for local energy markets?

18. How does a high cost of implementation of the local energy market affect the Customer segment?

19. How does a high cost of implementation of the local energy market affect the Value Propositions?

20. How does a high cost of implementation of the local energy market affect the Customer Relationships?

21. How does a high cost of implementation of the local energy market affect the Revenue Streams?

22. How does a high cost of implementation of the local energy market affect the Key Resources?

23. How does a high cost of implementation of the local energy market affect the Cost structure?

24. How does a local energy markets unable to comply with regulations impact the Customer segment?

25. How does a local energy markets unable to comply with regulations impact the Value Propositions?

26. How does a local energy markets unable to comply with regulations impact the Customer Relationships?

27. How does a local energy markets unable to comply with regulations impact the Revenue Streams?

28. How does a local energy markets unable to comply with regulations impact the Key Activities?

29. How are the Channels affected if the participants are unwilling to adopt the local energy market?

30. How are the Customer Relationships affected if the participants are unwilling to adopt the local energy market?

31. How are the Revenue Streams affected if the participants are unwilling to adopt the local energy market?

32. How are the Key Activities affected if the participants are unwilling to adopt the local energy market?

33. How are the Cost structure affected if the participants are unwilling to adopt the local energy market?

Results
In the figure below the processed results of the questionnaire is provided.

Question:	DSO & Supplier	Prosumer
1	2	2.2
2	2.17	2.38
3	2.33	2.57
4	2.33	2.57
5	2.67	2.93
6	2.33	2.57
7	2.17	2.38
8	2.17	2.38
9	1.83	2.02
10	2.17	2.38
11	2.67	2.93
12	2.67	2.93
13	2.50	2.75
14	2.50	2.75
15	2.33	2.57
16	2.17	2.38
17	2.67	2.93
18	2.83	3.12
19	2.50	2.75
20	2.67	2.93
21	2.67	2.93
22	2.33	2.57
23	2.67	2.93
24	2.83	3.12
25	2.83	3.12
26	2.83	3.12
27	2.50	2.75
28	3.00	3.30
29	2.83	3.12
30	3.00	3.30
31	2.83	3.12
32	2.67	2.93
33	2.83	3.12

Results of the Questionnaire formatted in Excel